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MicroGrids and Electric Vehicles

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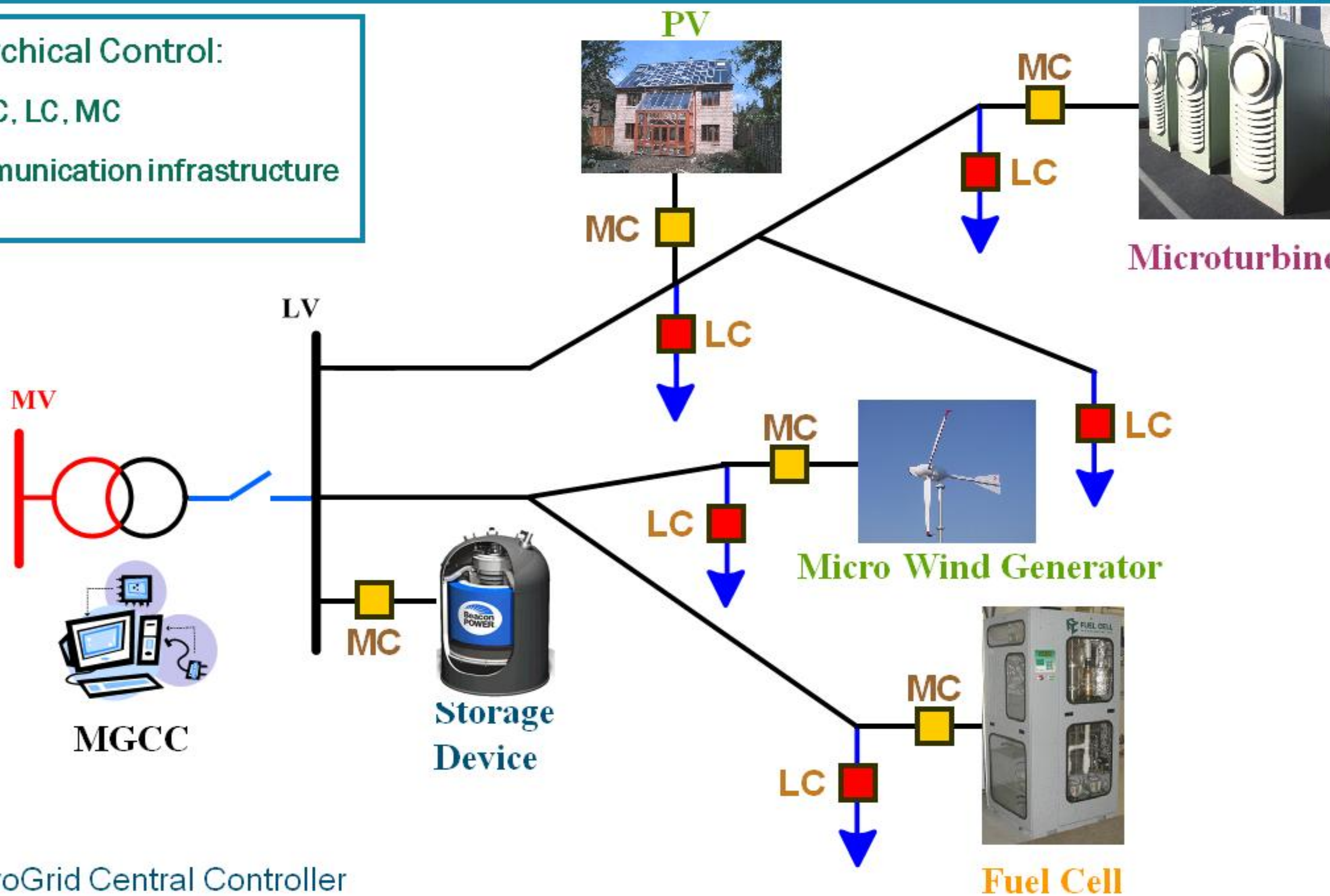
Contents

- MicroGrid Concept – an overview
- Integration of Electric Vehicles in the Distribution Grid
- Impacts resulting from EV connection – steady state analysis
- Exploiting EV regarding MG islanding operation

MicroGrid: A Flexible Cell of the Electric Power System

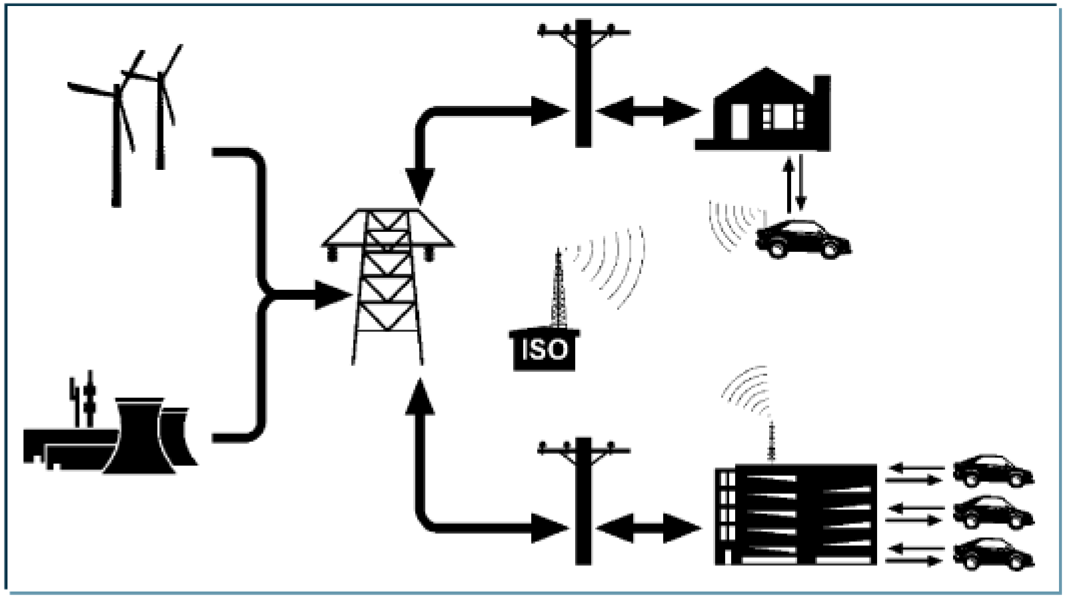
MG Hierarchical Control:

- MGCC, LC, MC
- Communication infrastructure



MGCC – MicroGrid Central Controller
MC – Microsource Controller
LC – Load Controller

V2G Concept



Kempton, 2005

Is this feasible?

How will the system behave?

Is the grid prepared?

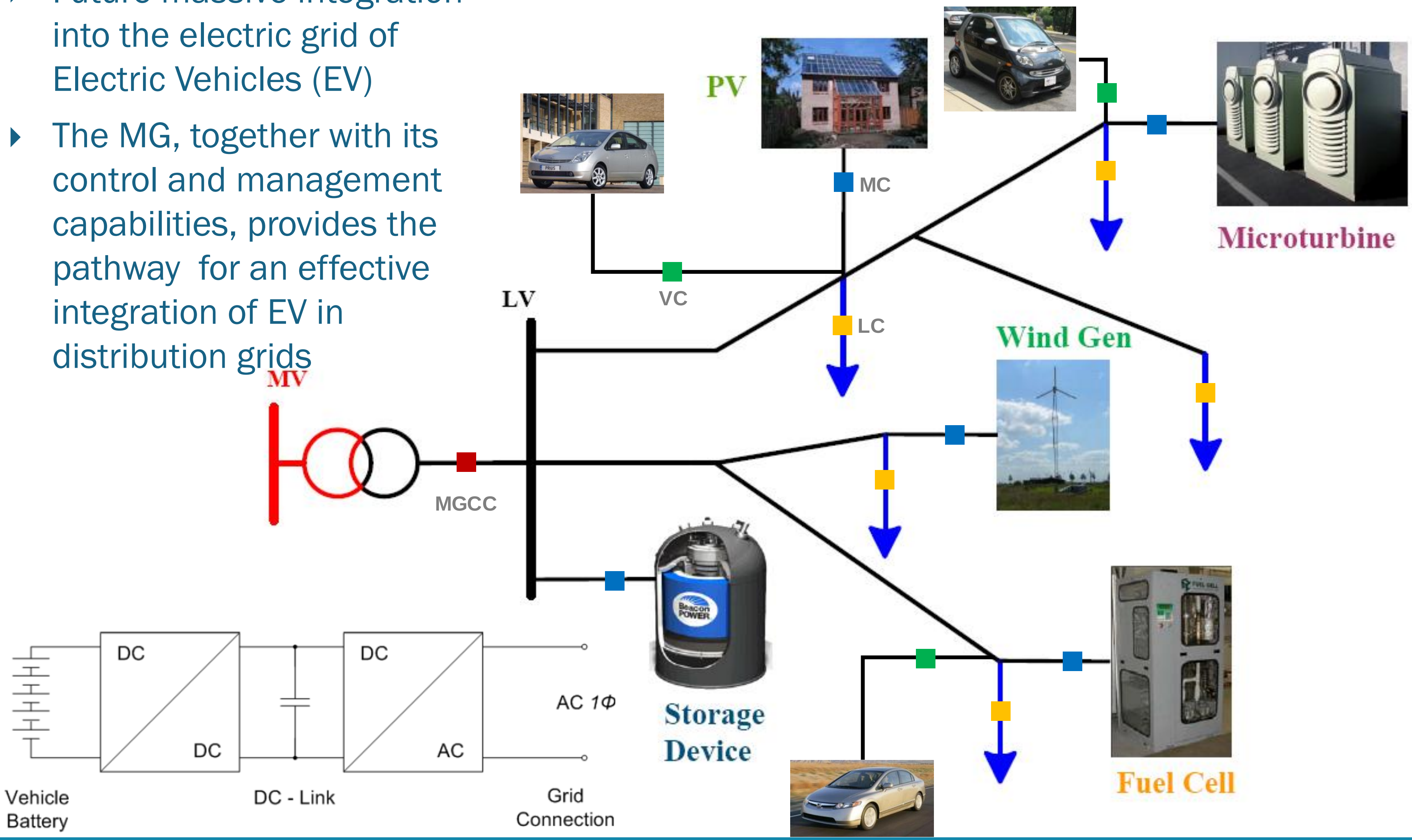
How will it benefit?

- Need to replace traditional fuels
- Need to store energy

- EVs used as storage
- Bidirectional power exchange with the grid
- Charging can be controlled accordingly with the markets
- Provision of ancillary services

LV grid of the future

- Future massive integration into the electric grid of Electric Vehicles (EV)
- The MG, together with its control and management capabilities, provides the pathway for an effective integration of EV in distribution grids



Exploitation of EV in the Electrical Power System

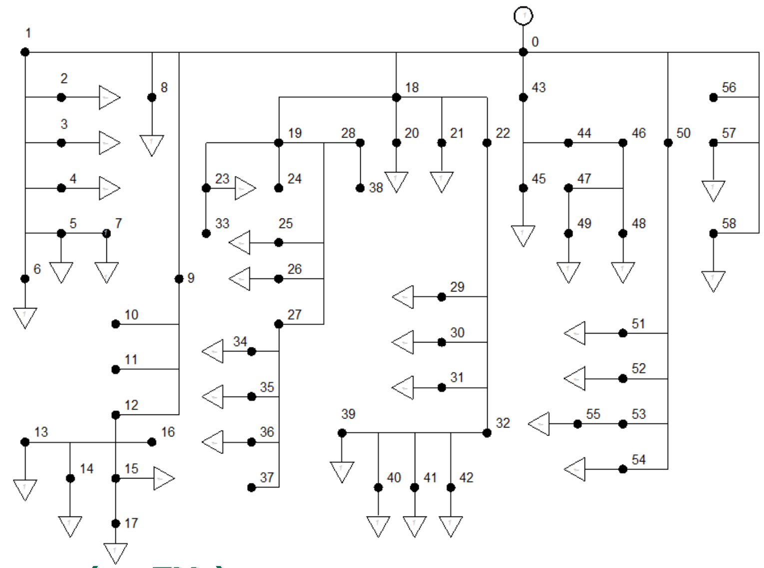
- In terms of Electrical Power Systems, EV can be regarded as:

- **Simple loads**, e.g. when their owners simply define that the batteries must be charged at a certain rate
  - It may represent a **large amount of energy consumption**, which represents an important share of the power consumed in a typical domestic household at peak load
  - Problems regarding **congestion** may arise at heavily loaded grids and **voltage profiles** in radial networks if the peak load periods coincide with EV charging

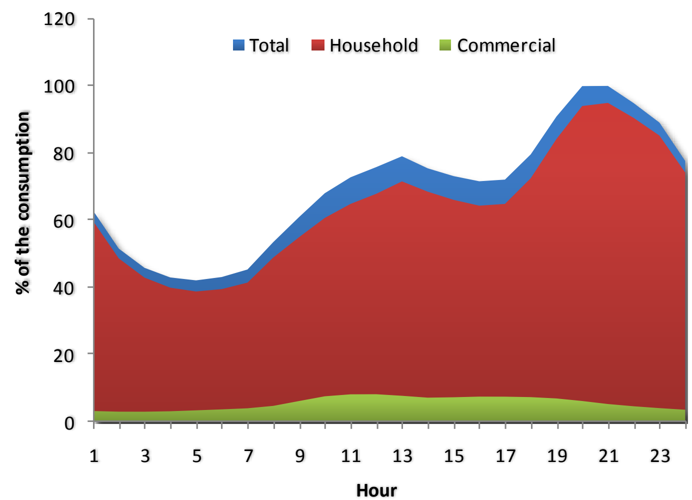
- **Dynamic loads/storage devices**, if their owners define a time interval for the charging to take place, allowing some EV management structure to control that process
  - From the grid point of view, this approach yields more **benefits** once it provides **elasticity** to these new loads
  - Greater potential benefits from large EV adoption: EV can be regarded as **distributed energy storage** that can be used in **ancillary service provision**

Study Case – a LV distribution grid

- Residential LV network (400 V)
- Feeding point voltage → 1 p.u.
- Feeder capacity → 630 kW
- 250 households
- 9.2 MWh/day
- 550 kW peak load

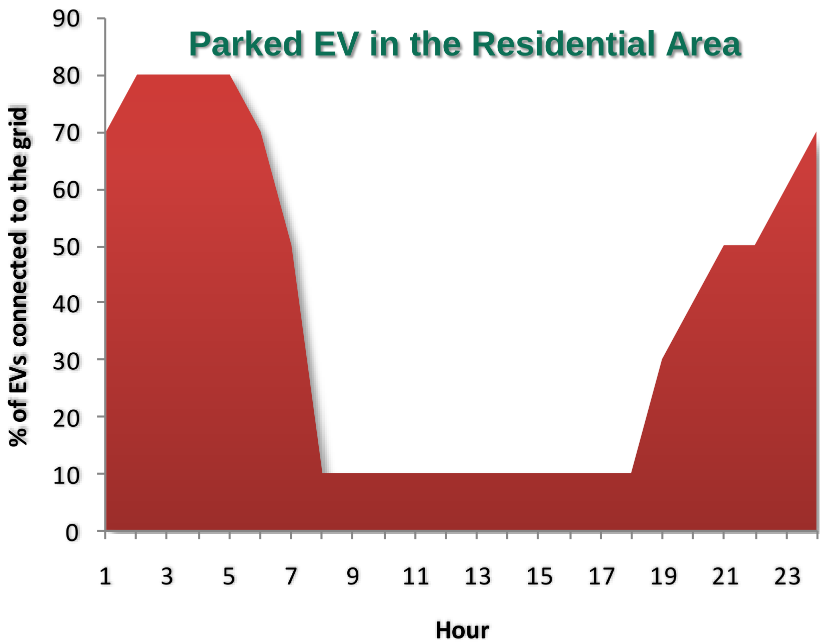


Grid Load Diagram (no EVs)



Study Case – a LV distribution grid

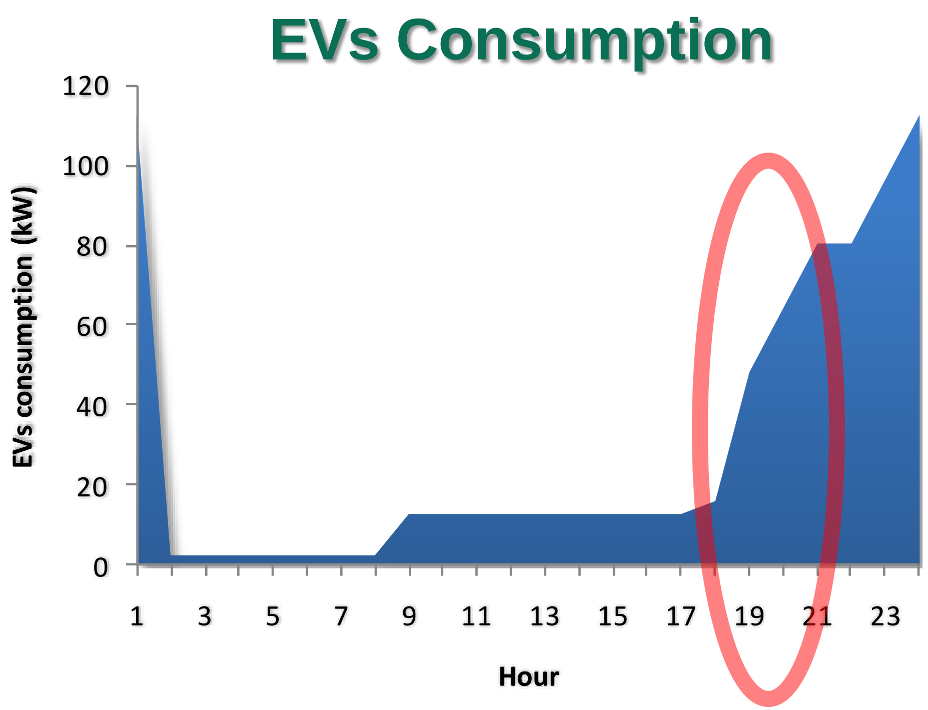
- Scenario Definition
  - 375 vehicles (total number of vehicles)
  - EVs charging time → 4h
  - EVs fleet consumption:
    - Large EV (EV1) → 24 kWh
    - Medium EV (EV2) → 12 kWh
    - Plug-in Hybrid EV → 6 kWh
  - Worst case scenario: EVs charge their batteries in the same day



Scenario	0	1 (Dumb charging limit)	2 (Smart charging limit)
N.º of Vehicles	375	375	375
EVs %	0%	**11%**	**61%**
N.º of EVs	-	41	229
PHEV Share	-	20%	30%
EV1 Share	-	40%	40%
EV2 Share	-	40%	40%
Energy consumption for the selected day (MWh)	9.17	9.81	12.74

Allowable EVs integration without grid reinforcements

11%

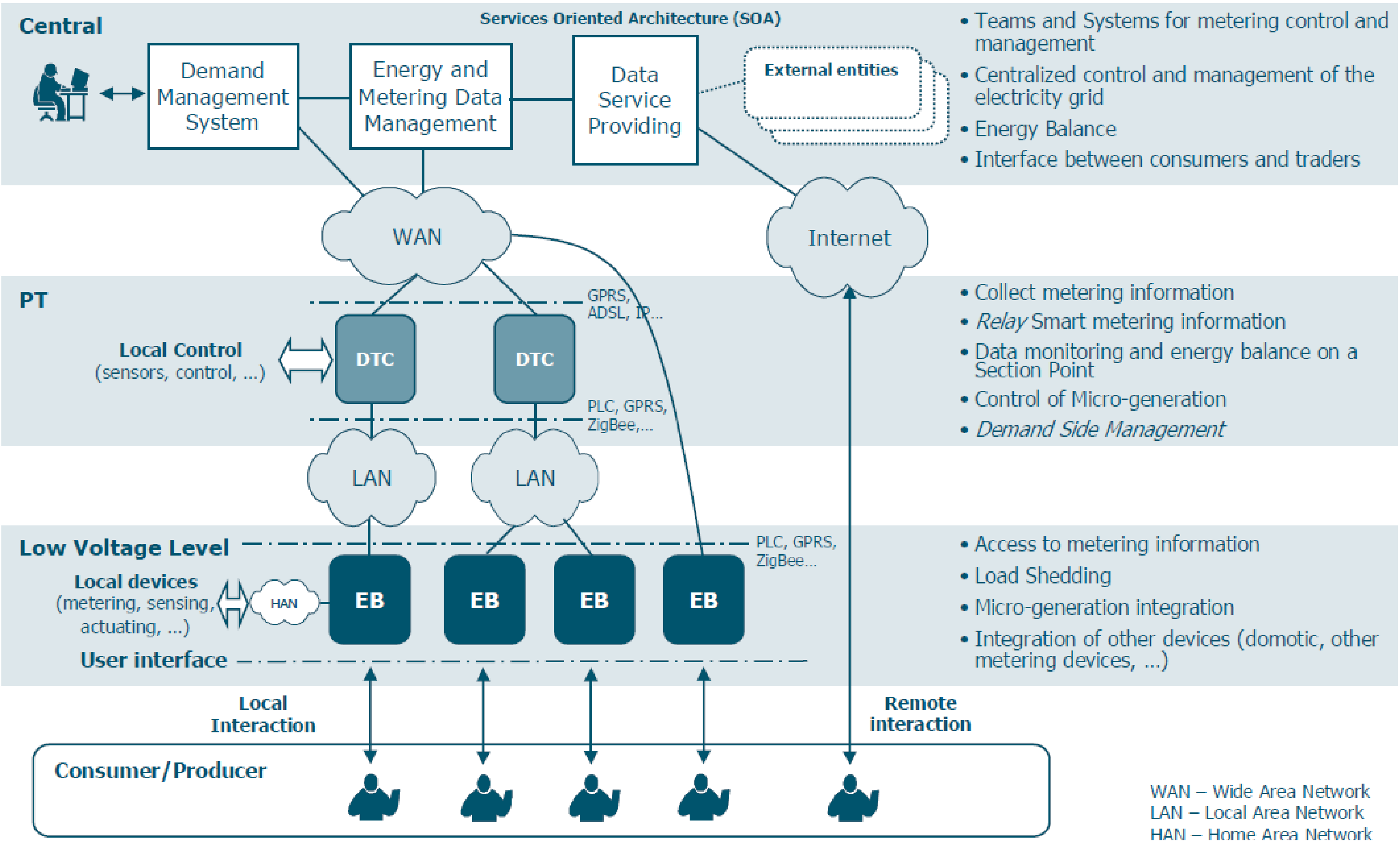


When people arrive home from work

Study Case – Adopting a Smart Charging Approach

Using smart meters is the most rational option – The MicroGrid concept is the base

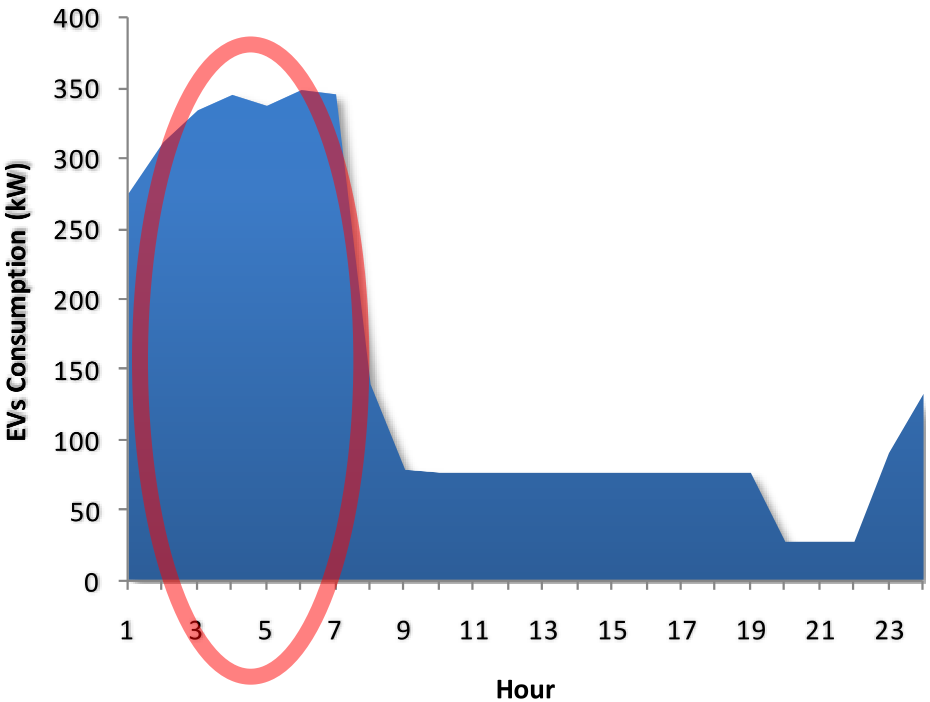
6 millions of smart meters will be deployed in Portugal in a near future (InovGrid Project)



Allowable EVs integration without grid reinforcements

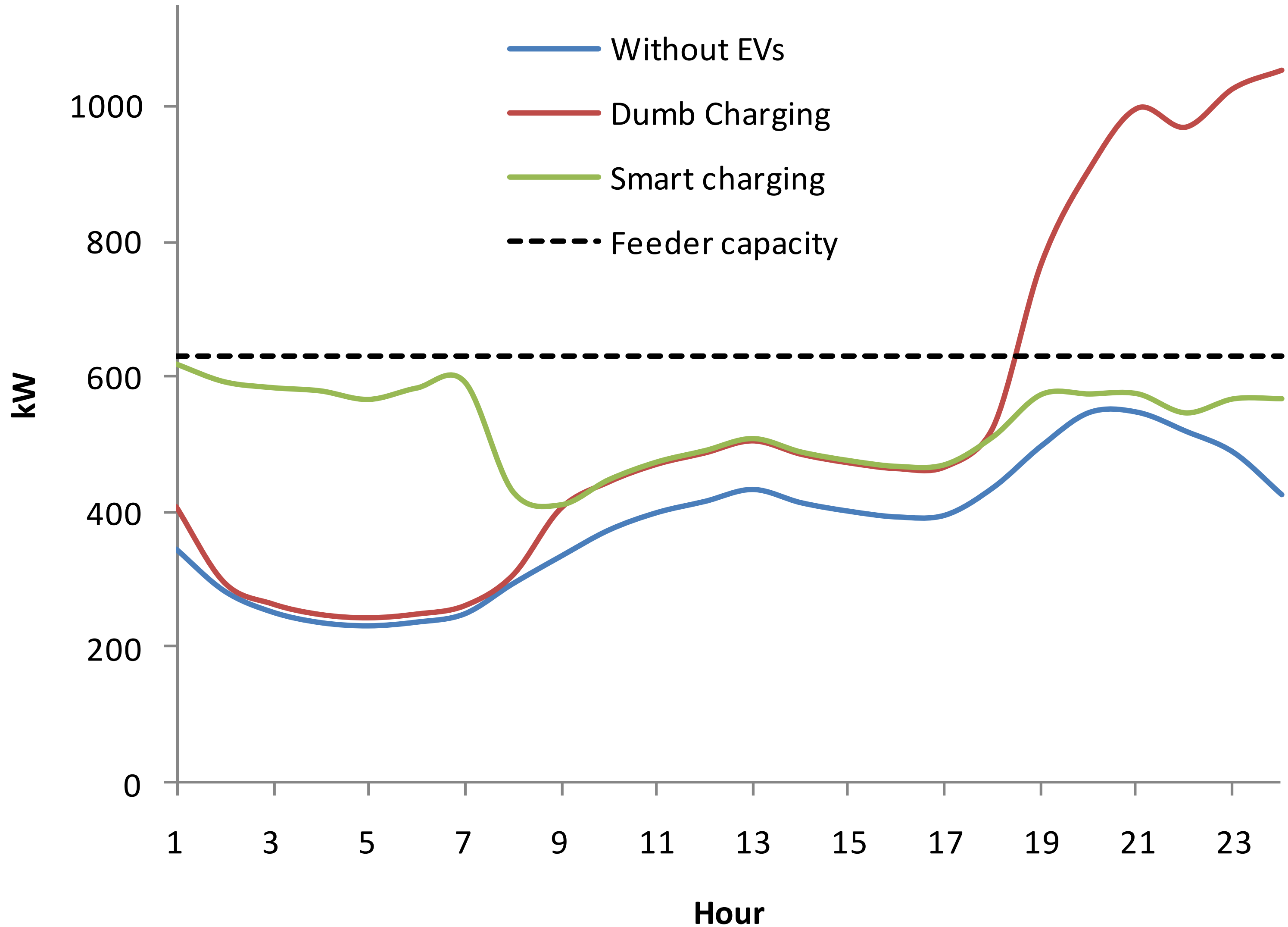
61%

EVs Consumption



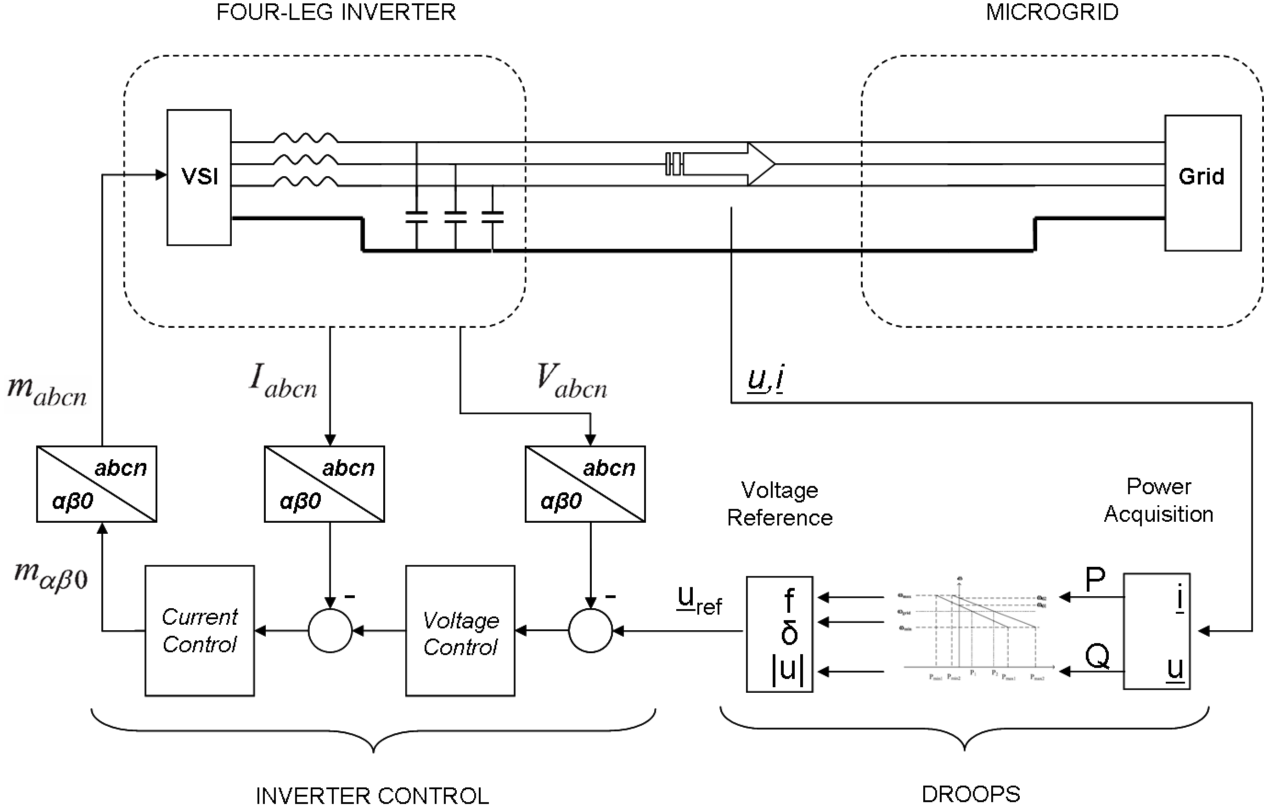
Avoids peak load increase

Study Case – EV connection under different Approaches



Control Strategies for MG with EV in Islanding Mode

- Energy storage is a key issue to allow MG islanding operation
- Battery charging devices for EV are assumed to be single phase, coexisting with normal single-phase loads and single-phase micro-sources, such as PV
  - Need to address issues related to voltage unbalance – Voltage balancing unit

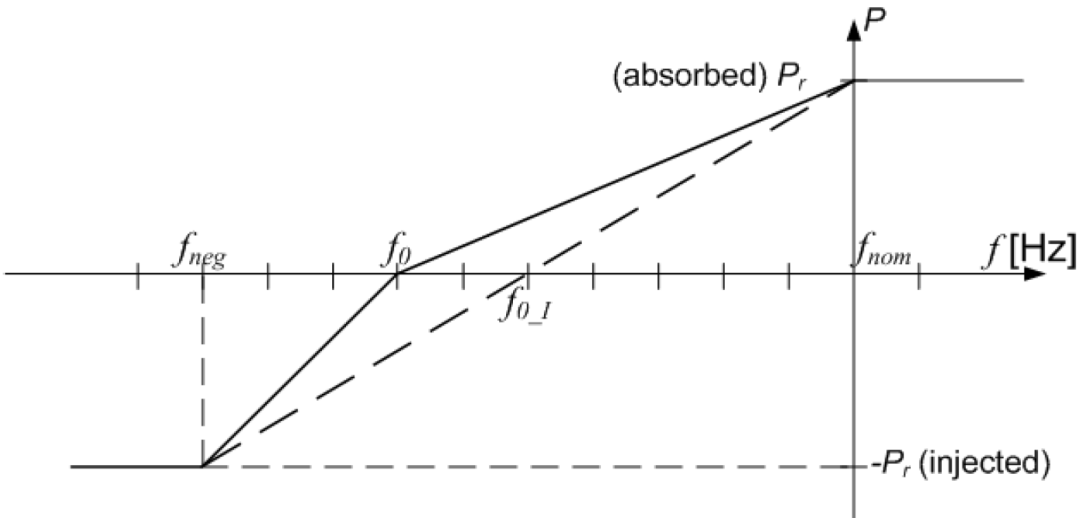


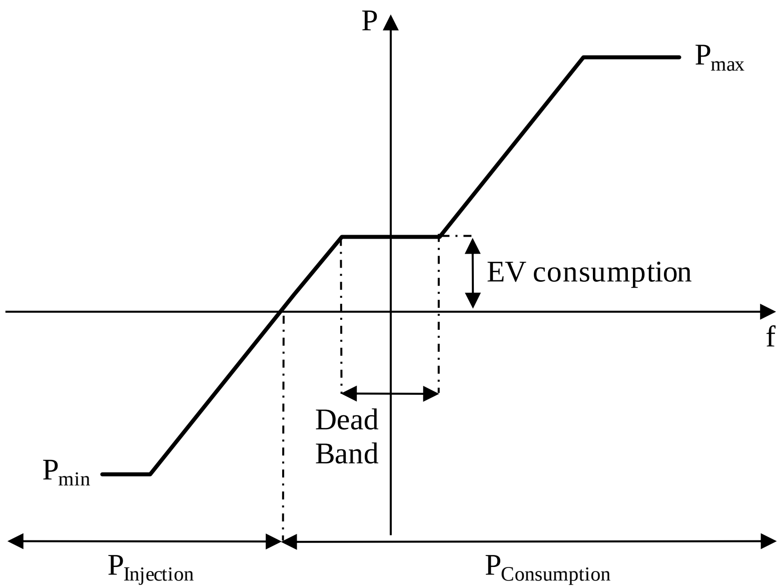
Control and Management Strategies for MG with EV

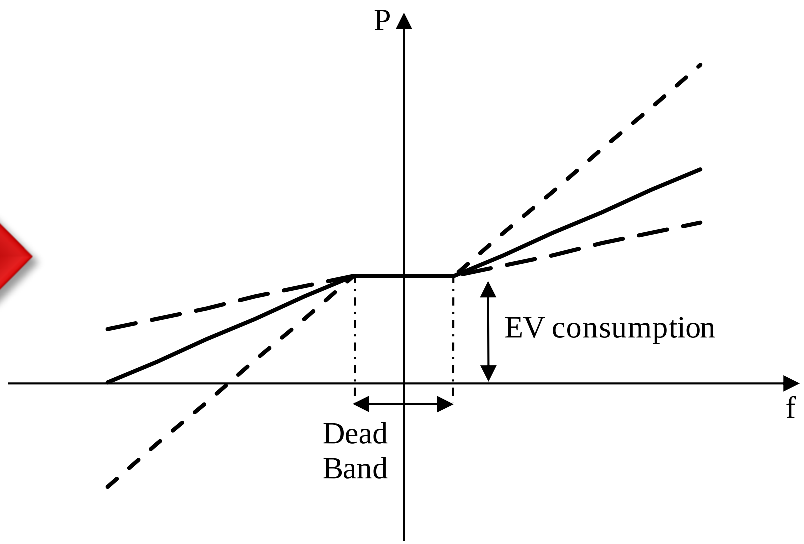
- During MG islanding operation, **frequency is an instantaneous indication of the power balance/imbalance in a MG**
  - It can be used in order to adapt the active power charging of EV batteries

- **Possible approaches for MG control during islanding**
  - EV charge up their batteries, at nominal frequency (and above): they absorb power at nominal charging rate
  - The power consumption is linearly reduced to zero when the frequency drops. The zero-crossing frequency, f_0, is a parameter of free choice.
  - If the system frequency drops further, the devices start to inject power into the system.

Control and Management Strategies for MG with EV

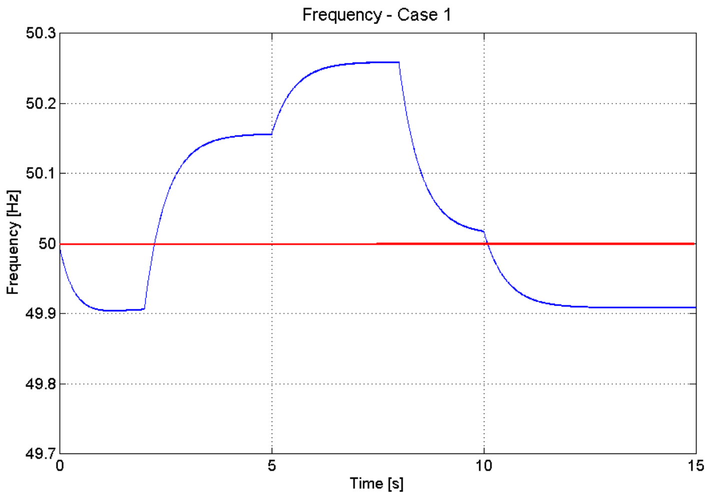




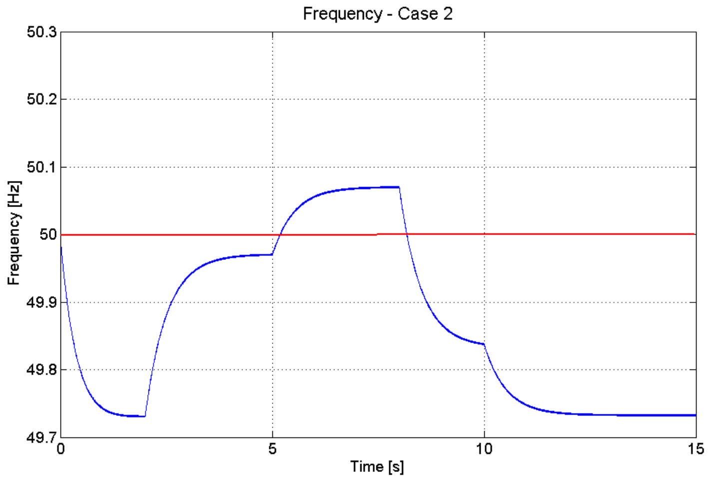


MG islanded Operation – Simulation Results

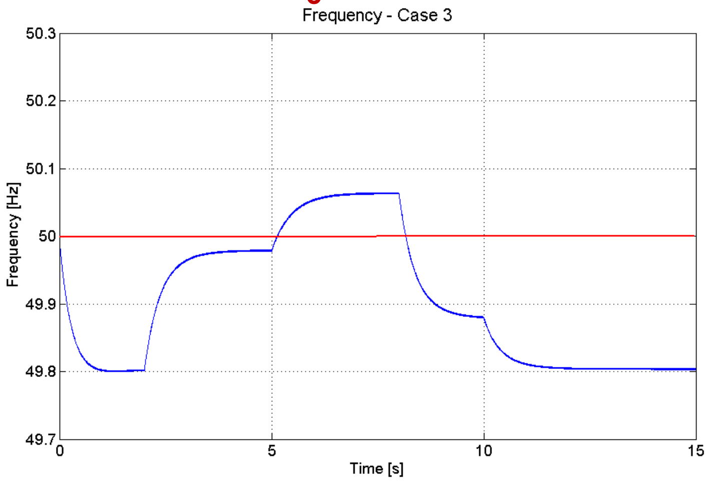
Whithout V2G



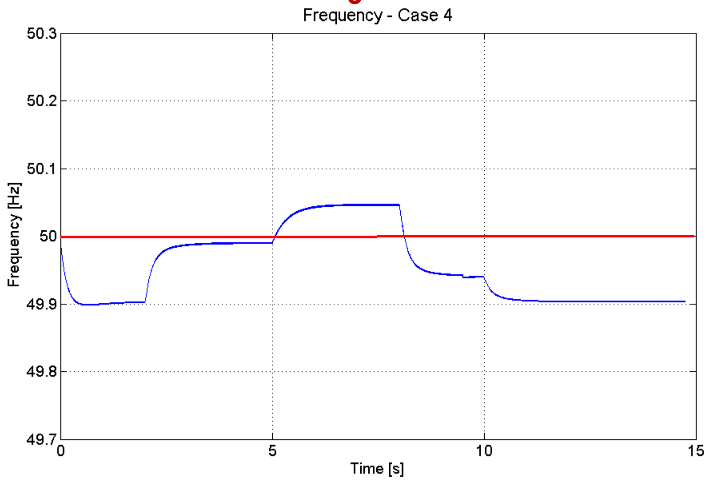
V2G with fixed charging rate



V2G - f_0 = 49.5 Hz



V2G - f_0 = 49.9 Hz



Control and Management Strategies for MG with EV

- EV contribution for voltage balancing in islanded MG
  - V2G control based on power set points from a central control device to each EV or group of EV
- Implementation:
  - active power exchange between the three-phase storage unit and the MG is measured in each phase
  - Set points to be sent to the V2G devices connected in phases a, b and c in different nodes of the MG are centrally calculated by the MGCC that acts in secondary control manner

$$e_1(t) = P_{mes\_a}(t) - P_{mes\_b}(t)$$

$$e_2(t) = P_{mes\_b}(t) - P_{mes\_c}(t)$$

$$e_3(t) = P_{mes\_c}(t) - P_{mes\_a}(t)$$

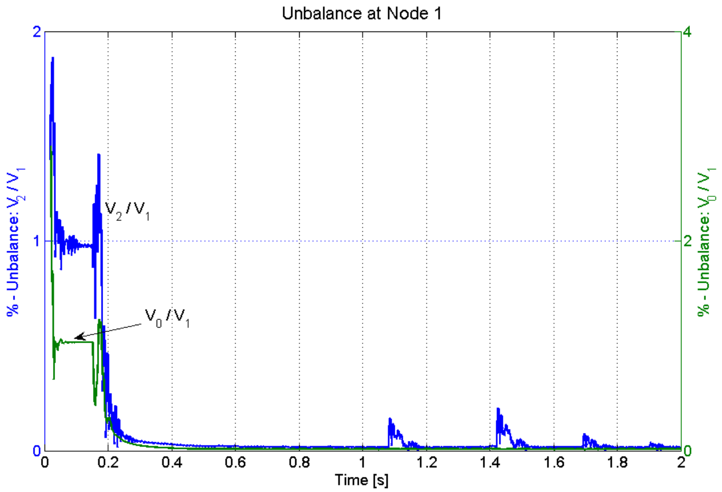
$$P_{set\_a}(t) = \int k \cdot (e_3(t) - e_1(t))\, dt$$

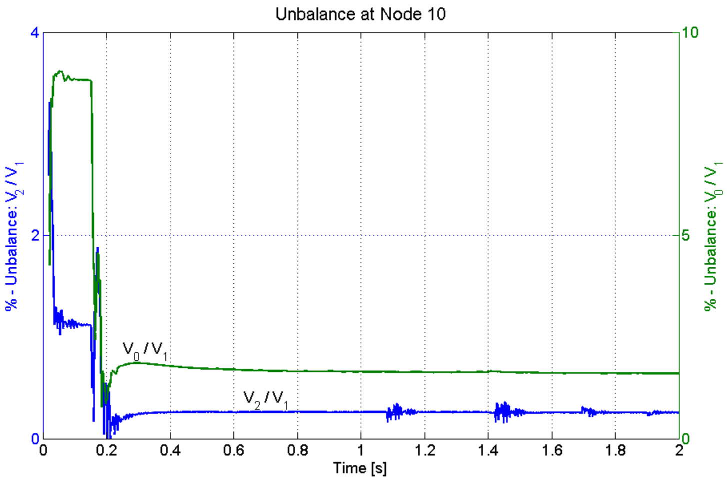
$$P_{set\_b}(t) = \int k \cdot (e_1(t) - e_2(t))\, dt$$

$$P_{set\_c}(t) = \int k \cdot (e_2(t) - e_3(t))\, dt$$

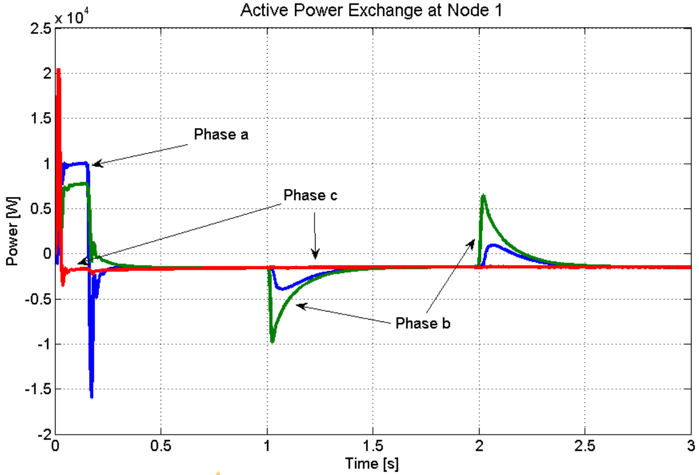
The development this expressions in positive, negative and zero-sequence components shows that the set points P_{set_a}, P_{set_b}, P_{set_c} reach a stable value only when all negative and zero-sequence voltages (and currents) become zero.

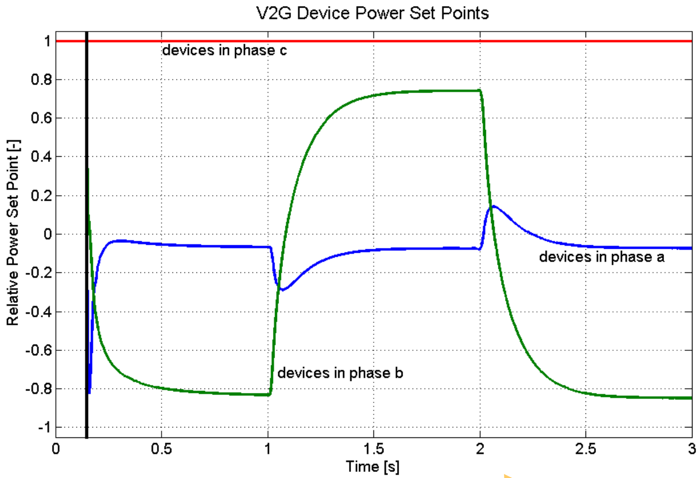
Unbalance improvement in MG islanded Operation





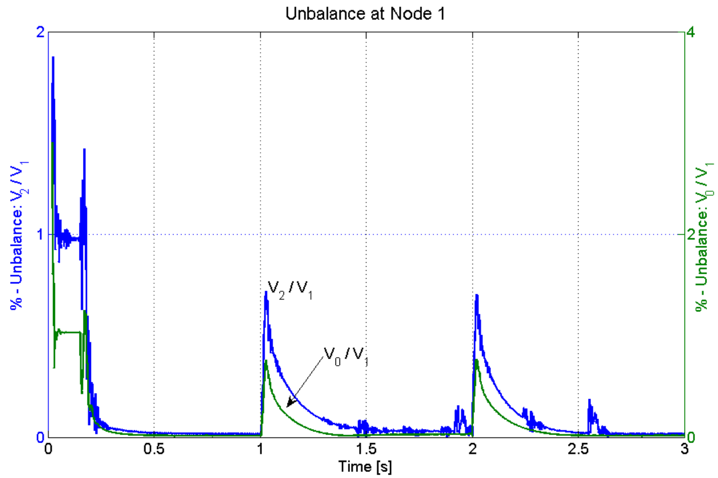
Load Following





Active Power in the Storage Unit

Set Points for EV



Voltage unbalance

Main Conclusions

- The adoption of Smart Charging strategies using the MG infrastructure is imperative in order to efficiently integrate large amounts of EV in actual distribution grids
- EV integration in MG is feasible without changing existing control mechanisms
- EV can provide considerable contributions for MG operation, namely:
  - Providing additional storage capabilities, which increases the resilience of MG operation
  - Contribution to improve voltage balancing during islanded operation, therefore improving power quality