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Distributed Generation and Microgeneration and its Impacts

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Scope

- I Distributed Generation and Microgeneration and its technical impacts

- II Global evaluation of the impacts of a large scale microgeneration penetration

Introduction

- Driving forces for the future development of the electric energy systems:
  - 1) Environmental issues: meet Kyoto protocol targets (reduce emissions by replacing fossil generation by zero emission generation, reduce network losses), minimize visual impacts and land use.
  - 2) Replacement of old infrastructures (generation and grid)
  - 3) Security of Supply
  - 4) Increase quality of service (more automation and remote control)
  - 5) Electricity market liberalization (energy and services)

⇓

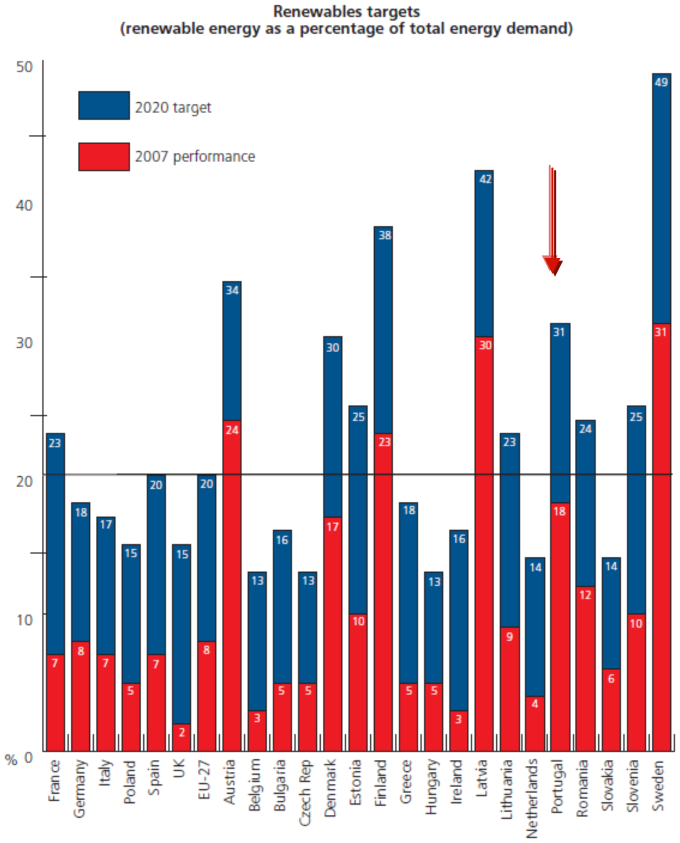
  - 1) Increase renewable generation, exploit clean coal technologies, CCGT and others
  - 2) Increase Distributed Generation
  - 3) Demand Side Management (increase load consumption efficiency)

Introduction

- More recently European leaders have agreed to a legally binding objective to meet 20% of their energy needs with renewable such as wind power in a fresh drive to put the EU on track to a low-carbon economy by 2020.
  - This means intensive use of resources like: **biomass, hydro, wind, solar.**
  - This means intensive use of distributed generation.

Introduction – The new targets on RES

- European member states with a significant share of electricity requirements being met by renewable power sources → (DG resources)



50% - 55% target on electricty generation from renewable power sources defined for Portugal [REN]

I - Distributed Generation and Microgeneration - New Paradigmas

- **The vision**

Introduction

- Distributed Generation (DG) has attained a considerable penetration level in HV and MV networks, involving different types of sources and conversion technologies;
  - The most relevant ones are:
    - Mini-hydro using synchronous or asynchronous generators;
    - Cogeneration using mainly synchronous units;
    - Biomass generation units with synchronous generators;
    - Wind generation, exploiting conventional asynchronous or DFIM units and synchronous units with electronic converters.
  - Usually these generation devices do not participate in voltage control and frequency regulation
  - Current practice is based on a “fit and forget” approach, which provokes:
    - Negative impact in the deployment rate of DG;
    - Increases costs of investment and operation in the networks;
    - Undermines integrity and security of the system.

Introduction

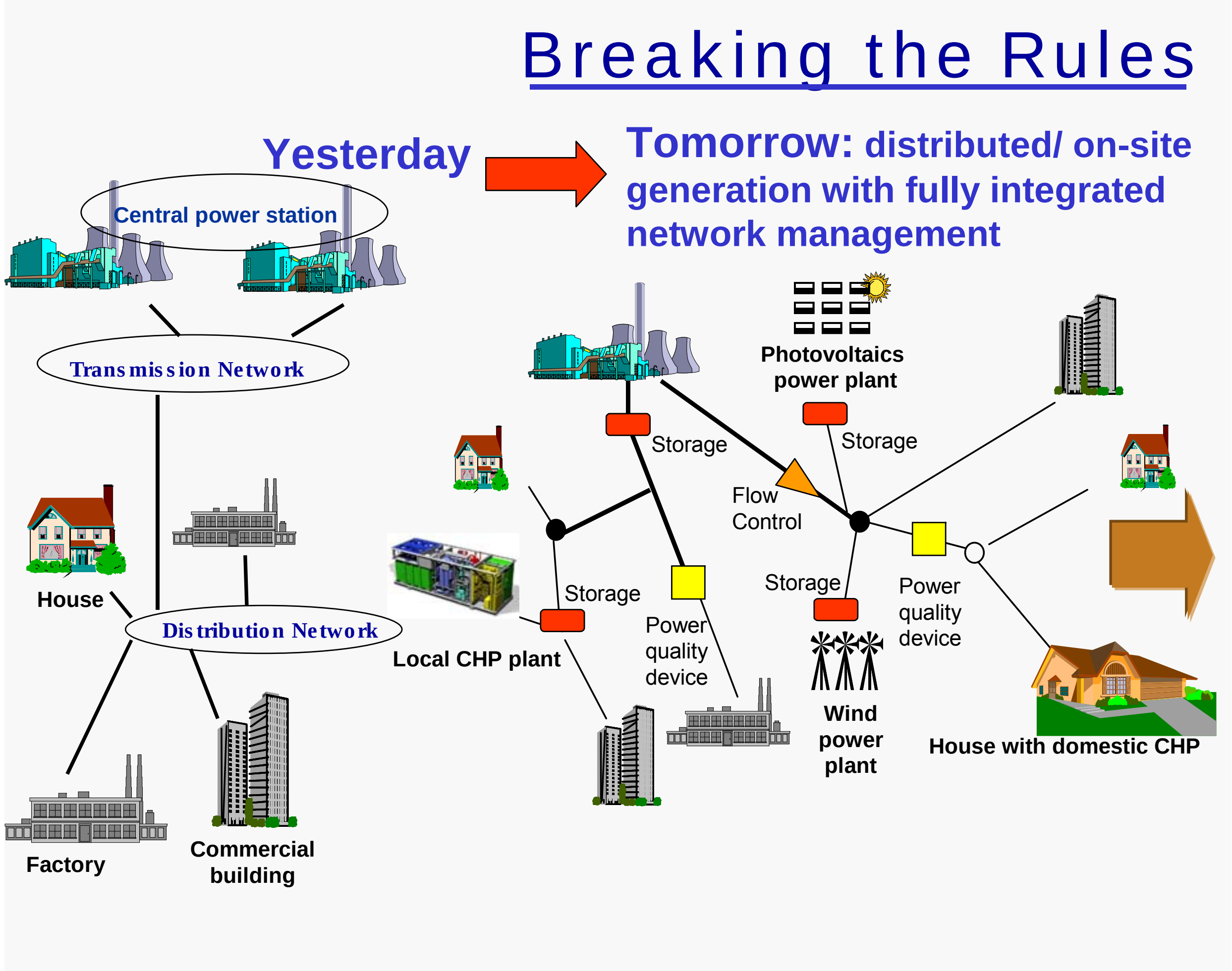
- The change of paradigm that DG introduced started at the MV level;

A more ambitious change

- Microgeneration directly connected to the LV network is becoming a reality:
  - Next 10 to 20 years:
    - The change that occurred in MV networks may also happen in LV networks:
      - Connection of small modular generation sources;
      - Typically in the range from 5 to 100 kW;
      - Fuel cells, renewable generation (wind turbines and PV systems), micro turbines (natural gas or bio fuels);
    - LV networks are also becoming active;

Introduction

- New paradigmas are under development



Current distribution grid

Management practice

needs to be changed

from passive to active –

<u>DG control paradigm</u>

Technical problems in distribution grids

- Load flows may become bi-directional;
- Voltage profiles have different patterns;
- Losses change as a function of the production and load levels;
- Congestion in system branches is a function of the production and load levels;
- Short-circuit levels increase;
- Voltage transients may appear as a result of connection disconnection and operation of generators;
- Risk of non controlled islanding operation;
- Power quality and reliability may be affected;
- Utility protections need to be coordinated with DG ones.

Characterization of DG units

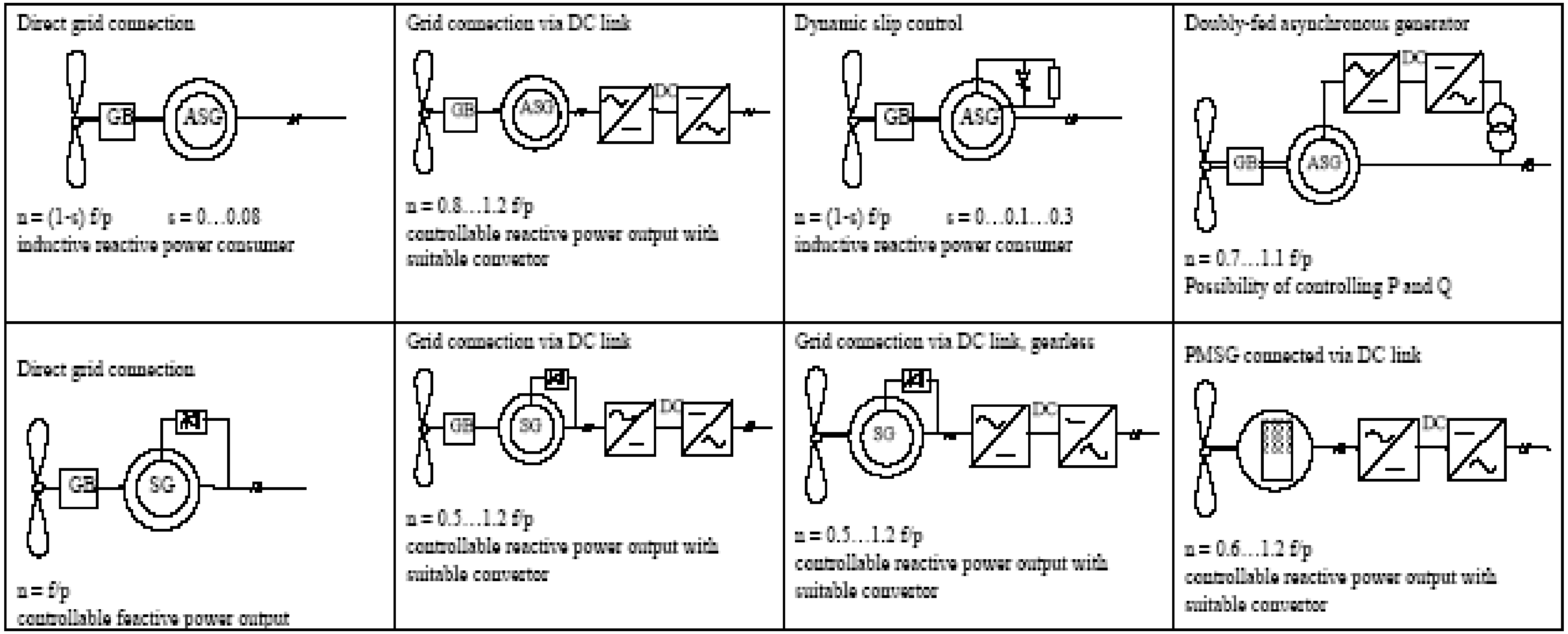
- Three main types of energy conversion systems can be found among DG units:
    - Conventional synchronous machines (cogeneration, CHP, mini-hydro, biomass);
    - Asynchronous generators (wind power, mini-hydro);
    - AC/DC/AC electronic conversion systems used together with synchronous or induction machines (micro-turbines, fuel cells, wind generators, wave systems).

Characterization of DG units

- Classification (according to primary energy source and conversion system used):
  - Non- controllable (Ex: Wind park with asynchronous stall generators);
  - Partially controllable (Ex: Wind park with synchronous variable speed gen. + AC/DC/AC converters and DFIM);
  - Controllable (Ex: Mini-hydro or Cogeneration plants with synchronous units).

Modelling DG for Dynamic Behaviour Analysis

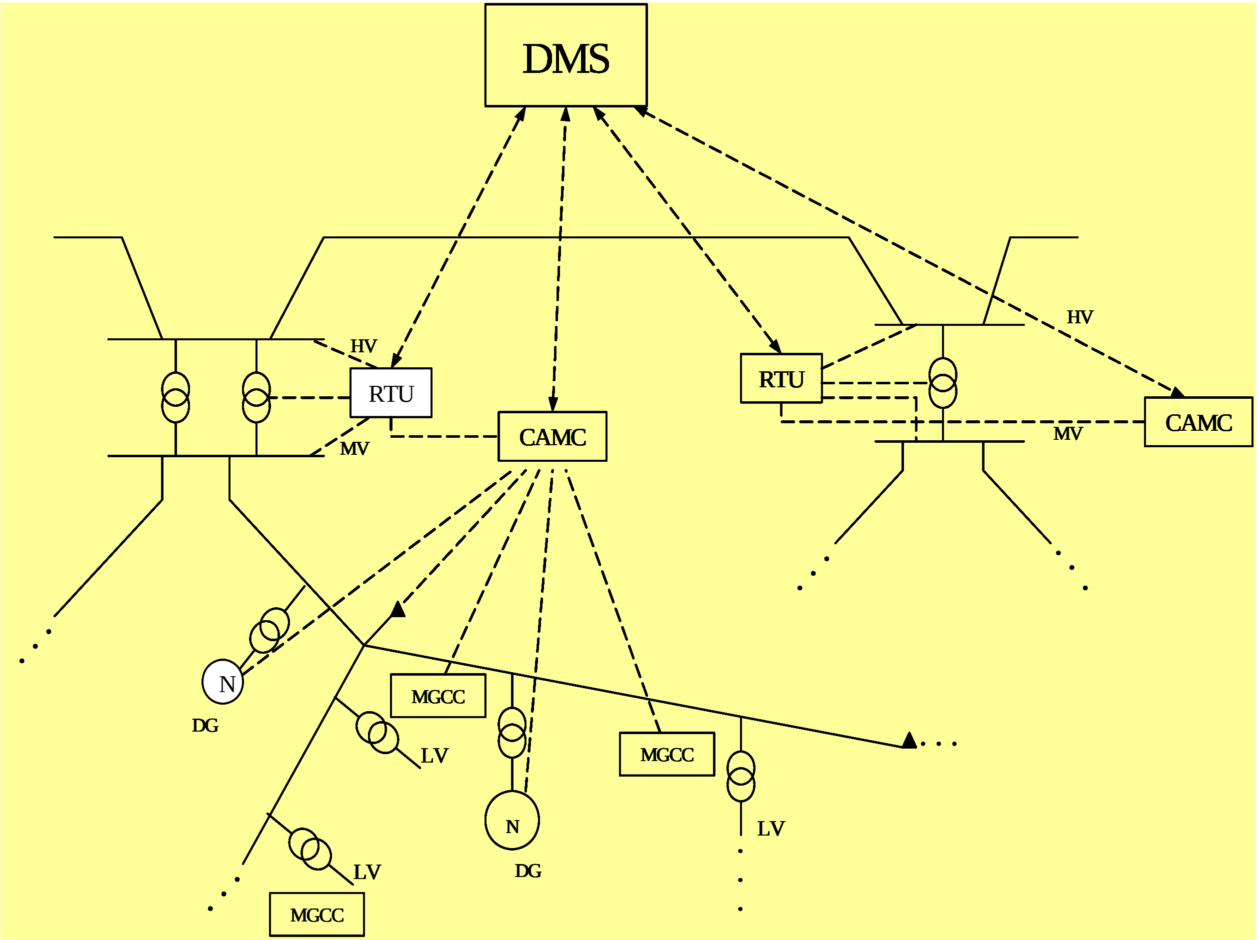
- DG units having synchronous generators can adopt the usual modeling with the presence of AVR and frequency regulator (to be activated for islanding mode of operation or in case of participation in frequency regulation);
- Wind generators (*CIGRE TF 38.01.10*)



Direct grid connection $n = (1-s)\, f/p$ $s = 0 \ldots 0.08$ inductive reactive power consumer	Grid connection via DC link $n = 0.8 \ldots 1.2\, f/p$ controllable reactive power output with suitable convertor	Dynamic slip control $n = (1-s)\, f/p$ $s = 0 \ldots 0.1 \ldots 0.3$ inductive reactive power consumer	Doubly-fed asynchronous generator $n = 0.7 \ldots 1.1\, f/p$ Possibility of controlling P and Q
Direct grid connection $n = f/p$ controllable reactive power output	Grid connection via DC link $n = 0.5 \ldots 1.2\, f/p$ controllable reactive power output with suitable convertor	Grid connection via DC link, gearless $n = 0.5 \ldots 1.2\, f/p$ controllable reactive power output with suitable convertor	PMSG connected via DC link $n = 0.6 \ldots 1.2\, f/p$ controllable reactive power output with suitable convertor

New paradigm of hierarchical distributed control

- Distribution Management Systems (DMS) need deal with controllability capabilities of large number of DG units



Participation of DG in Voltage VAR control

- DG can be used to optimise the operation strategy of distribution networks.

The Problem can be formulated an optimisation problem for the network such that:

Min (active power losses)

Subj. to:

$Vmax < V_i < Vmin$

$S_{ij}\ max < S_{ij}$

$Qgmax_i < Qg_i < Qgmin_i$ taking into account the type of generator

$Qimpor\ max < Qimpor$

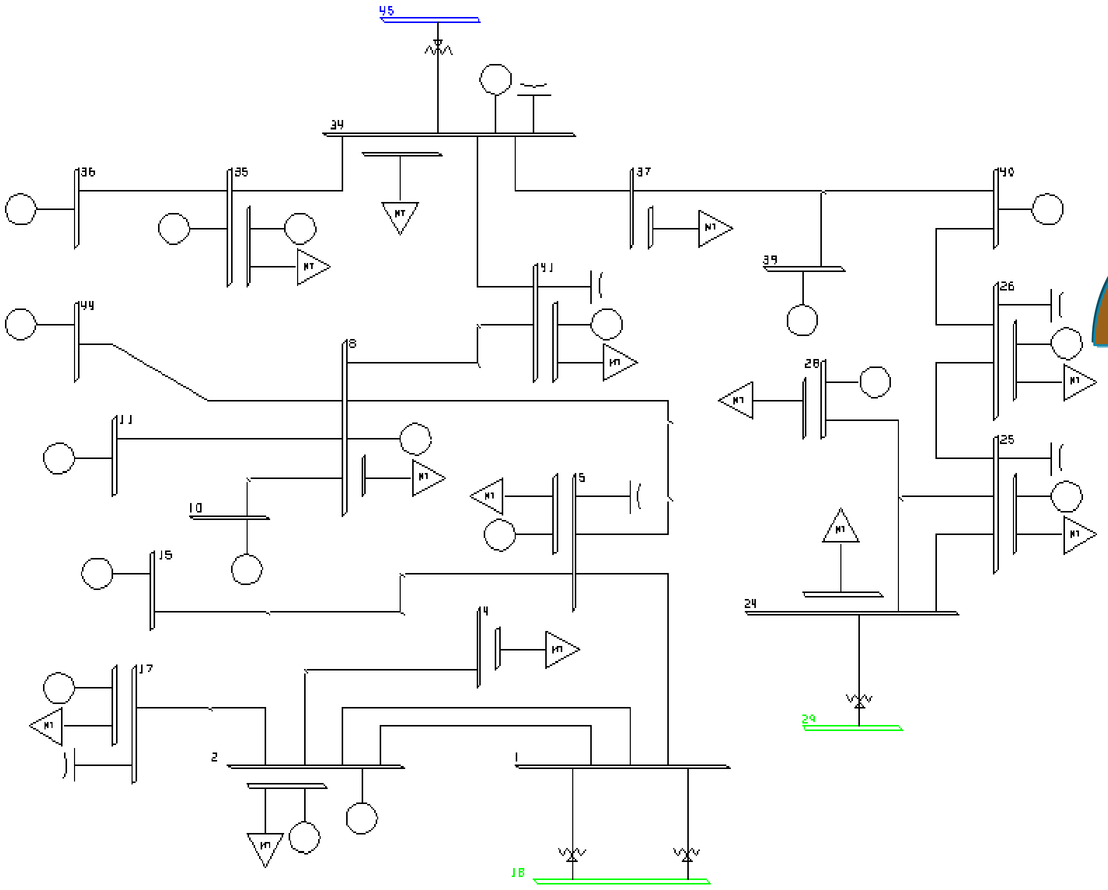
Transformer tap limits are kept

Control variables: Qg

➡ The need to use a motor of optimisation

Some results of the participation of DG in Voltage VAR control

- Test System: 60 kV distribution network with a large penetration of DG (mini-hydro and wind generation).



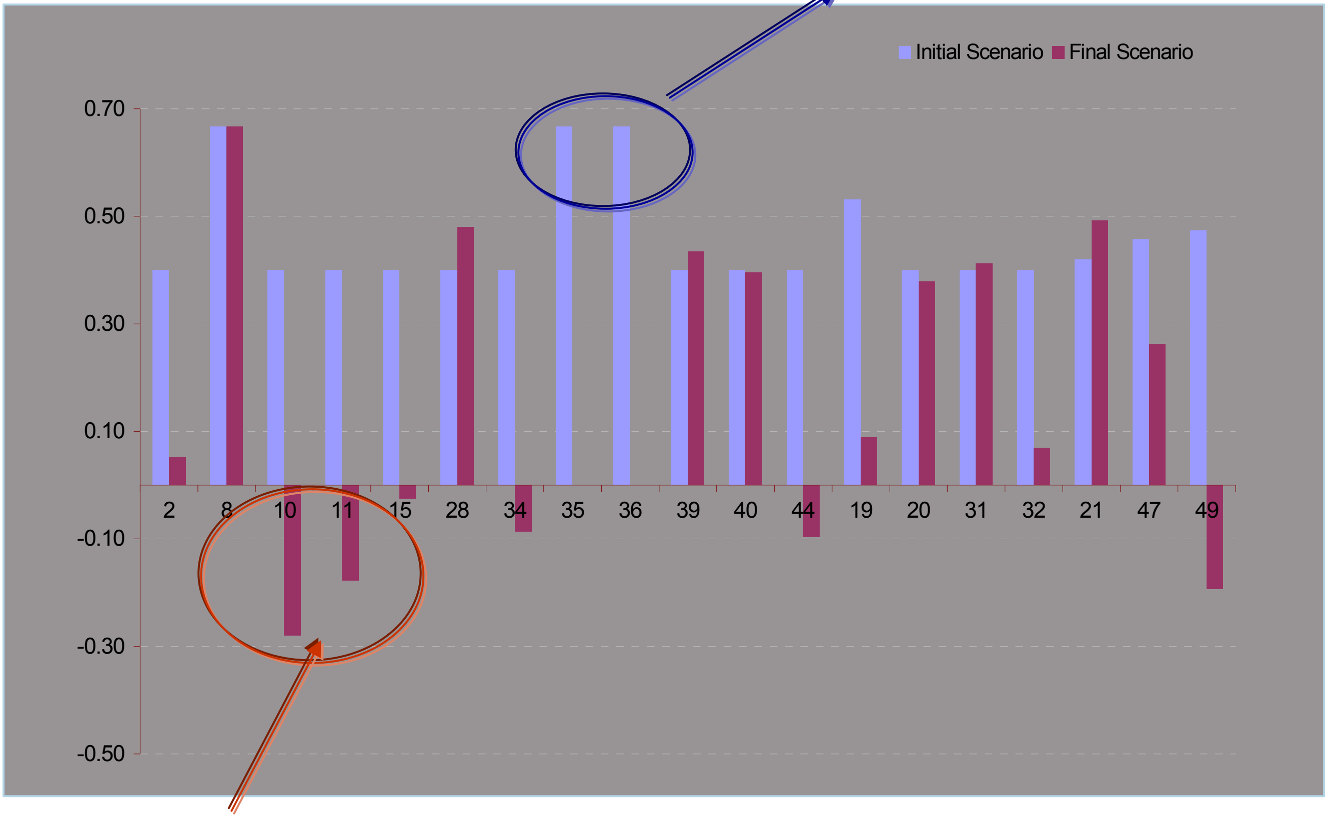
Activate control on reactive power generated in the DG Units.

Some results of the participation of DG in Voltage VAR control

Results of tgϕ for each generator and transmission connection

peak load scenario

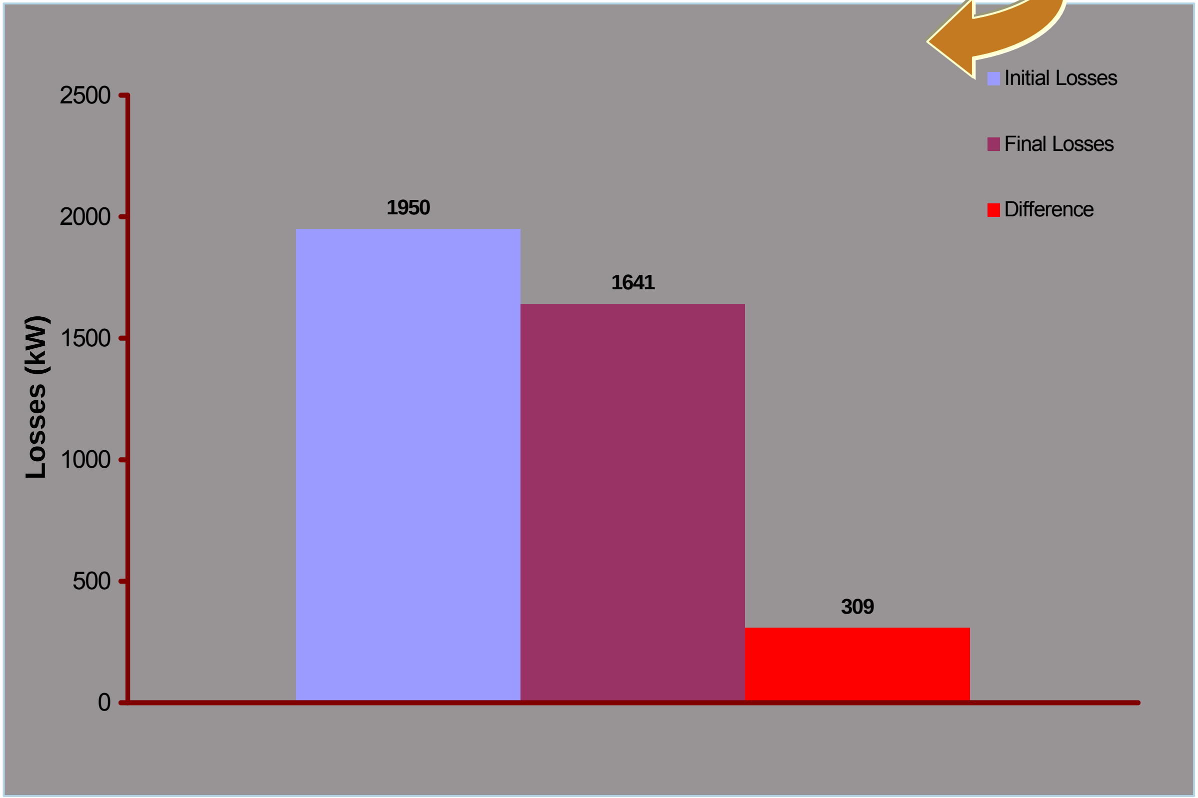
Asynchronous gen operating with product. level below nominal (Control through capacitor banks)



Reactive power absorption

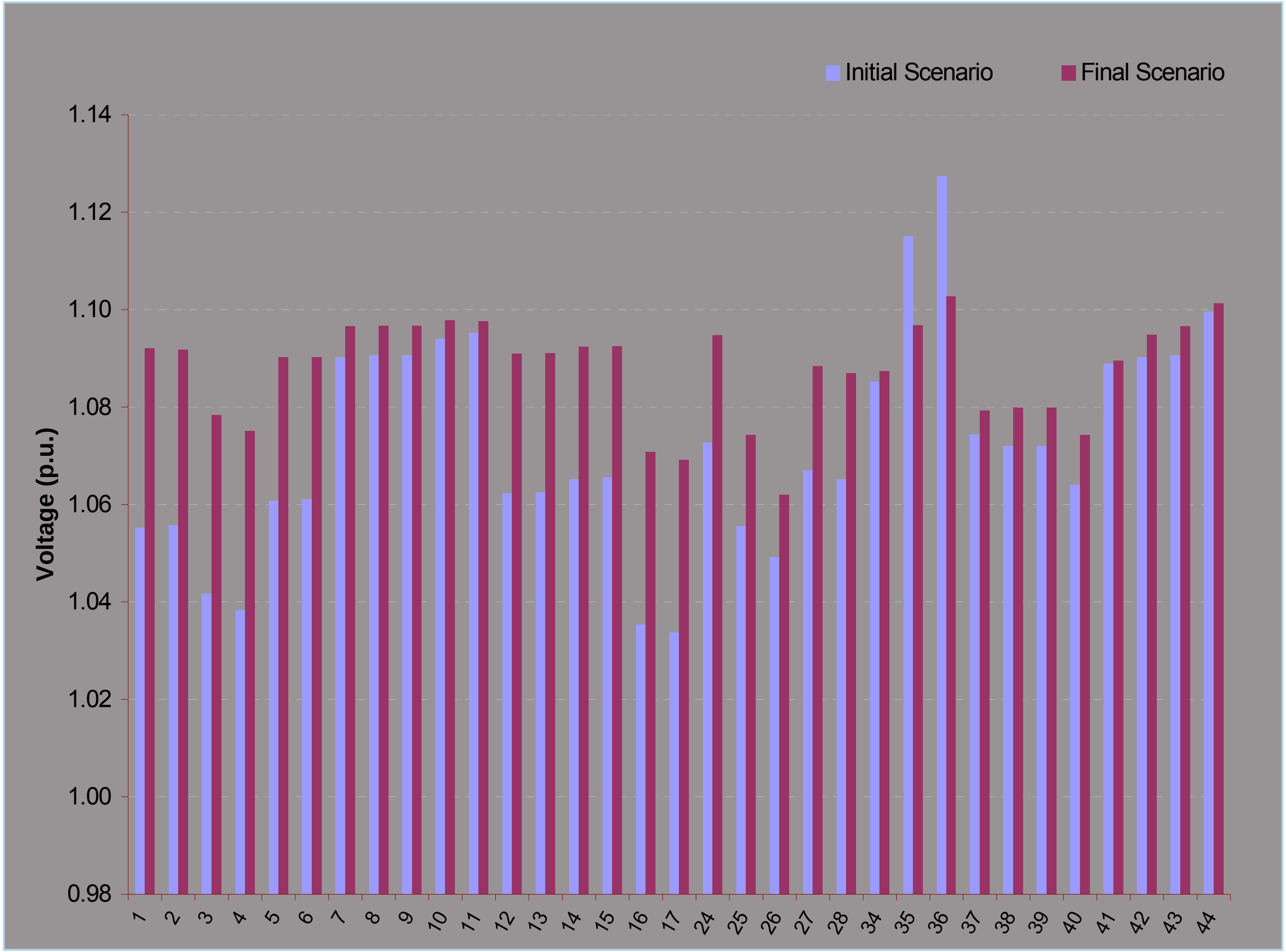
Some results of the participation of DG in Voltage VAR control

- Changes in active Losses
  - Peak load scenario
  - A clear reduction on actives losses was obtained



Some results of the participation of DG in Voltage VAR control

- Results concerning voltage in network busses



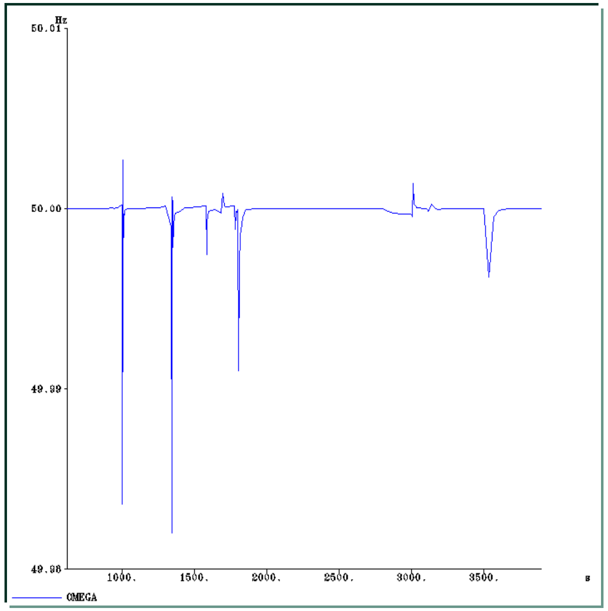
Some results of the participation of DG in Voltage VAR control

- Main conclusions
  - Active loses are clearly reduced;
  - Voltage levels increase, but violations are eliminated;
  - In general, reactive power production is reduced in generating units far from important loads or near loads *well* compensated;
  - In general, a reduction on load flow levels in network branches is obtained.

Islanding operation

- Programmed islanding when upstream grids need maintenance:
  - Availability of units capable of frequency regulation;
  - Additional monitoring and control capabilities;
  - Pre-balance between load and generation inside the island;
  - Relaxation of some settings of some relays (2 sets of settings are then recommended)

Frequency behaviour

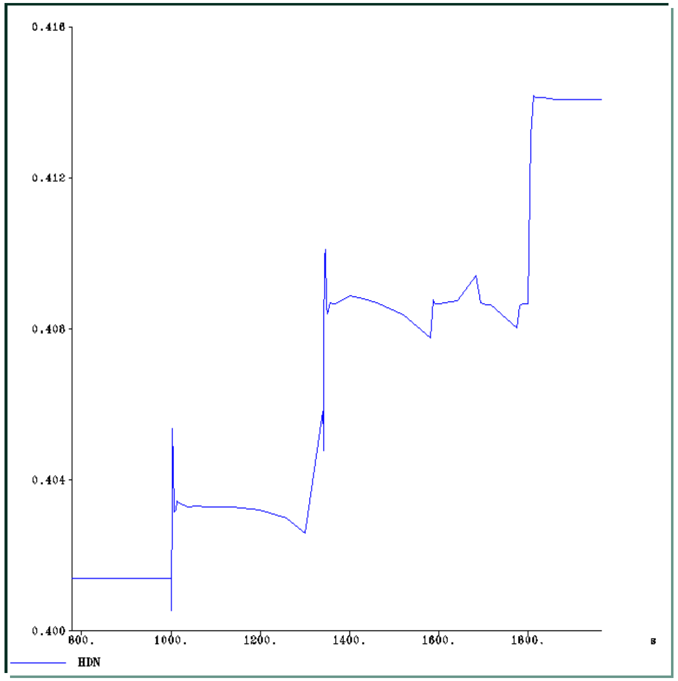


Islanding operation

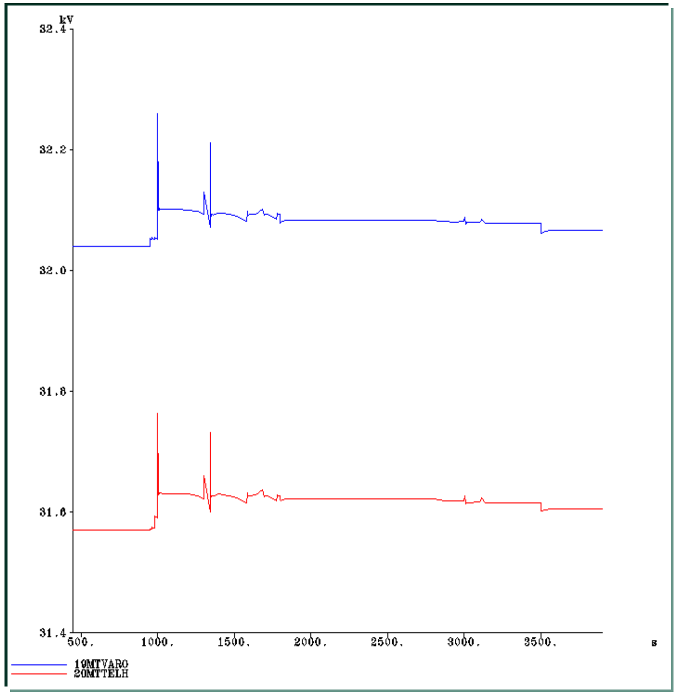
- Some simulation results from islanding operation in a distribution grid with wind generation, cogeneration and hydro units.

Response from one hydro

unit making frequecy regulation



Voltages in two buses of the grid



New Management tools in DMS

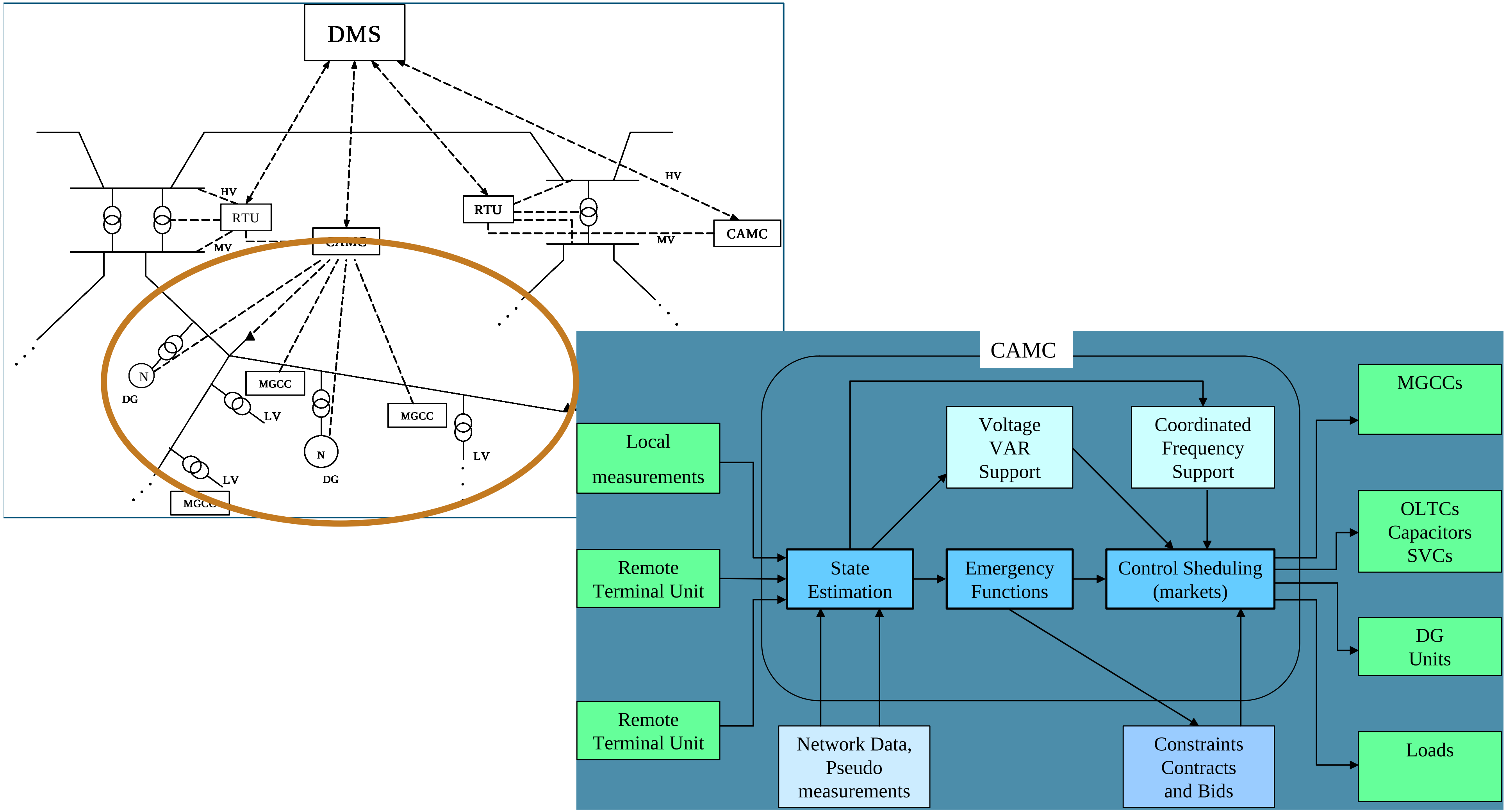
- In the short term change in control operating philosophy from central to distributed systems may increase overall costs;
- Increase communication capabilities to monitor and control better DG units and other grid devices;

⬇

- Voltage and VAR control tools are needed;
- New tools for network reconfiguration in operation optimisation and system restoration are needed, taking into account DG and their control capabilities;
- If interruptability of DG to deal with congestion management in the grids is to be allowed - specific management tools are needed;

New Management tools in DMS

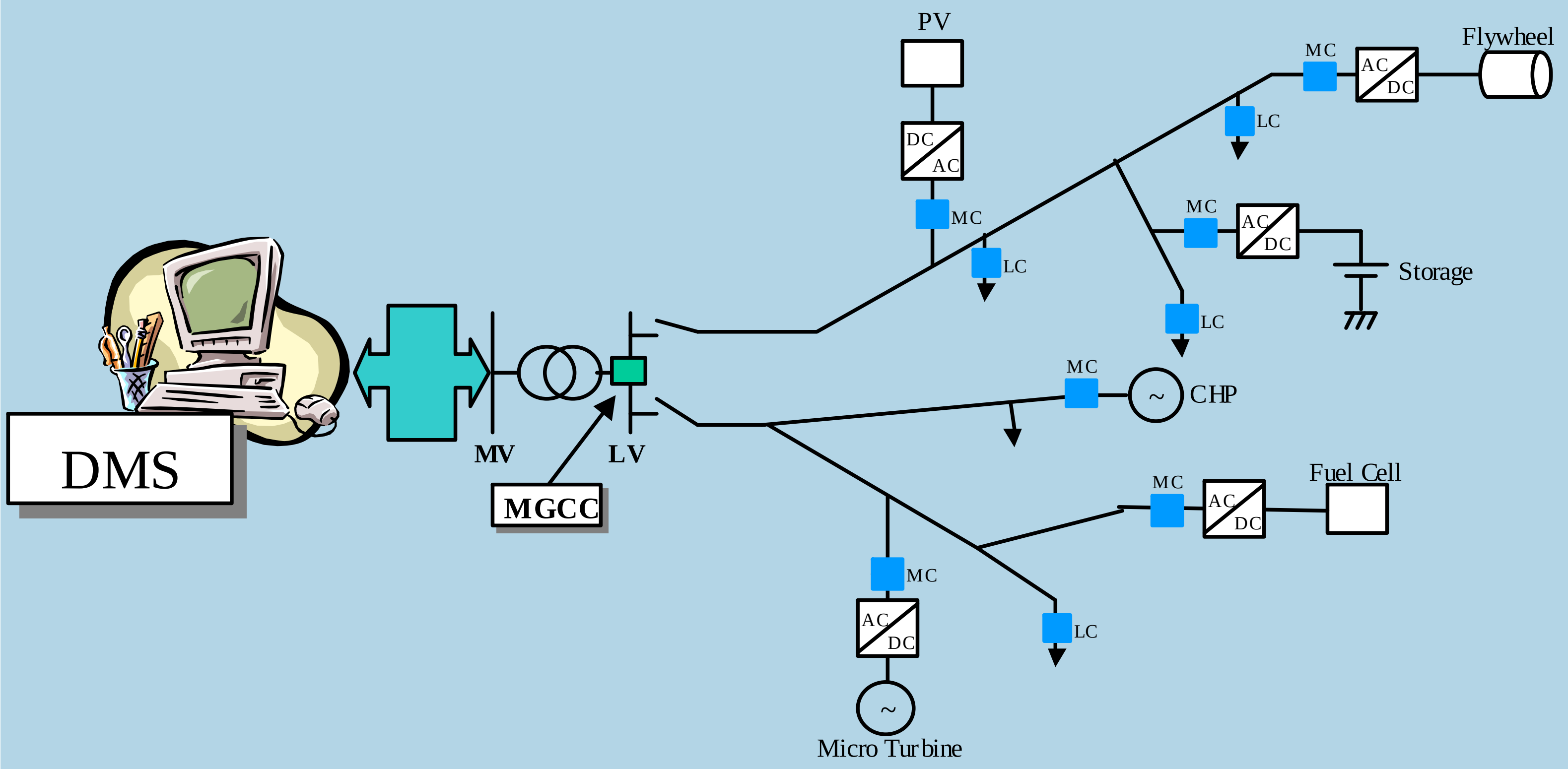
- Architecture and functionalities of CAMC



Microsources

- Microgeneration (to be connected at the LV level) is the new challenge for the electric power industry
- Microsources and storage devices:
  - Flywheels;
  - Microturbines (single shaft and split shaft)
  - PV panels
  - Fuel cells
  - Micro wind turbines;
  - Micro CHP.

The Microgrid concept



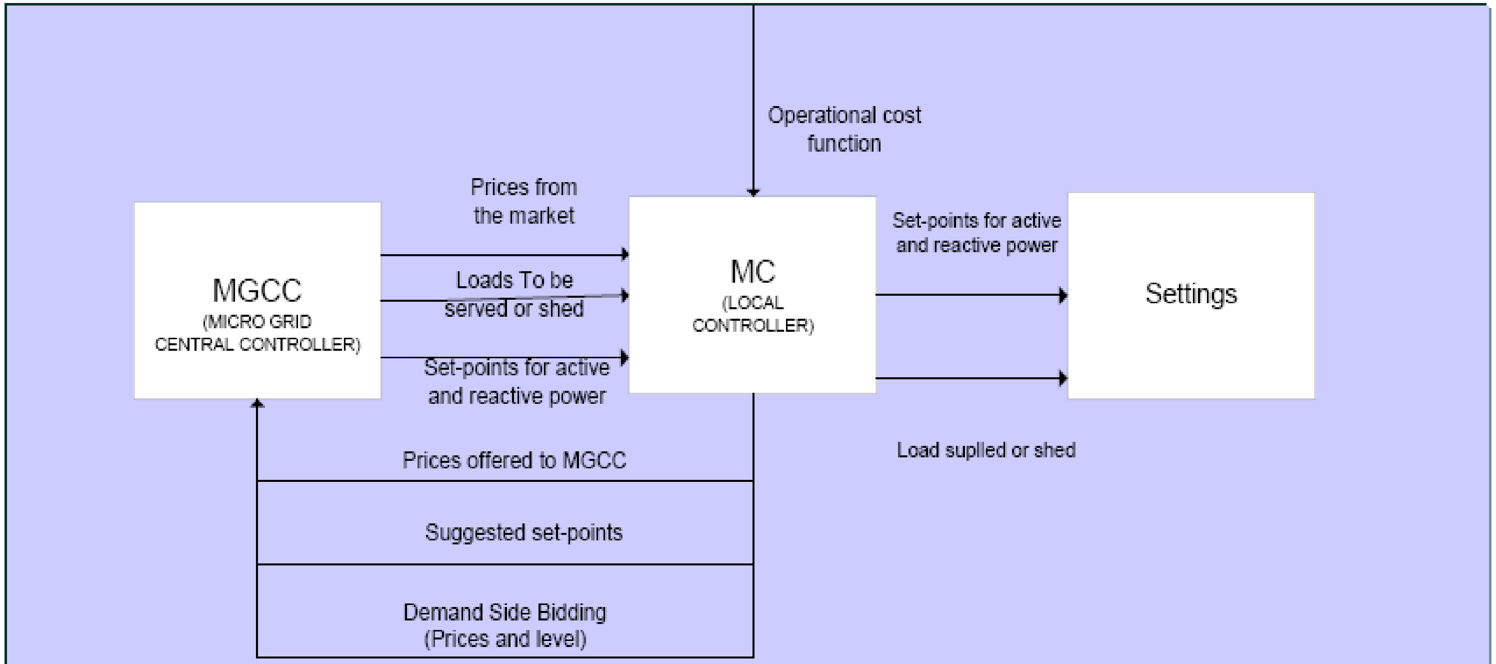
MGCC – Micro Grid Central Controller;

MC – Micro Source Controller;

L C – Load Controller.

Normal interconnected mode

- Managing the microgrid



Two market policies :

1.Microgrid as a good citizen-maintains zero reactive power serving its own customers needs

2.The Microgrid buys and sells power to the grid

MicroGrid Islanded Operation

- The MicroGrid can operate autonomously in case of
  - Failure in the upstream MV grid – forced islanding
  - Maintenance actions – intentional islanding
  - In this case the MGCC:
    - Performs frequency and voltage control in close coordination with the local controllers in order to not jeopardize power quality
    - Triggers a black start function for service restoration at the low voltage level if the MicroGrid was unable to successfully move to islanded operation and if the main power system is not promptly restored after failure removal

MicroGrid flexibility will contribute to the improvement of the energy system reliability and quality of service

II Global evaluation of the impacts of a large scale microgeneration penetration

- Investigate the impact of microgeneration on the Portuguese Electrical Distribution System
  - quantify overall benefits of microgrids in terms of energy losses and avoided CO_2 emissions
  - quantify the impact of a widespread deployment of microgrids on the future replacement and investment strategies → investment deferral

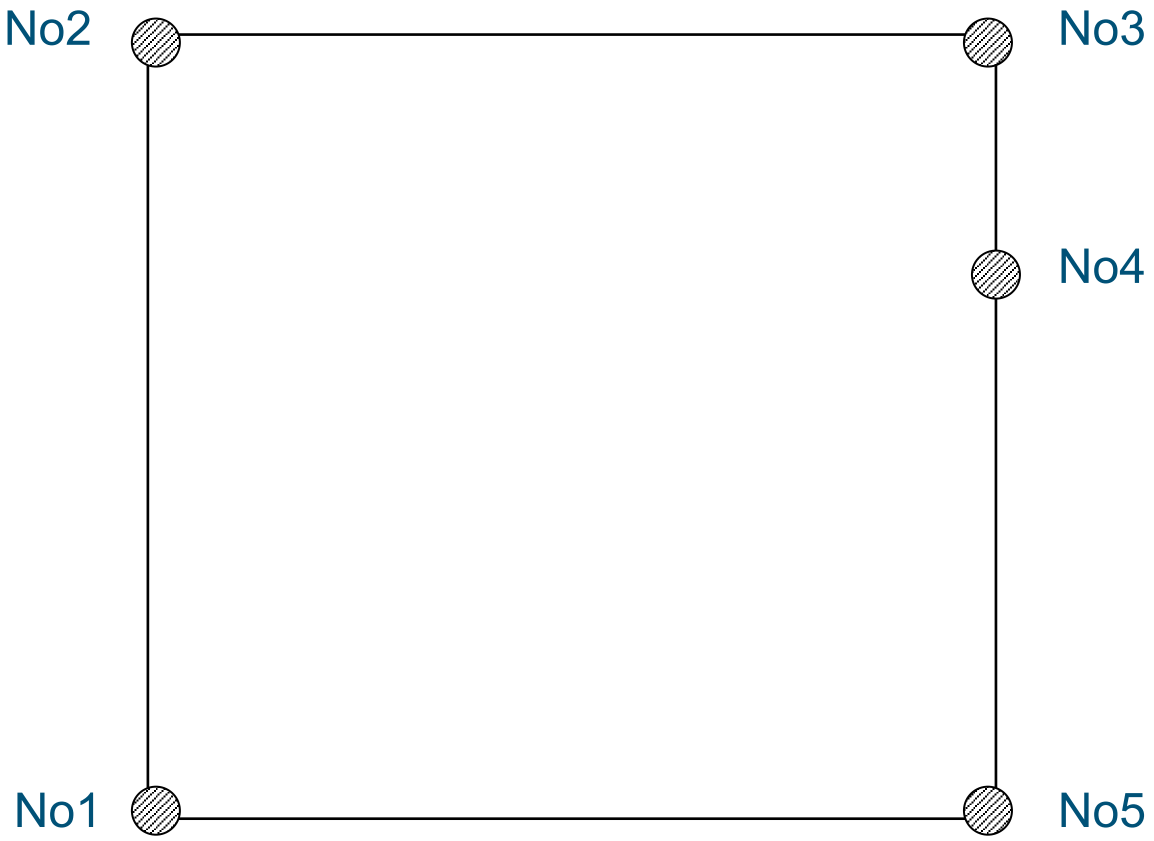
Methodology

- Hence, typical networks at the distribution level were identified (HV, MV and LV)
- For each network it was necessary to define:
  - load scenarios
  - microgeneration scenarios
- For each network, load and microgeneration do:
  - Calculate losses, by solving load-flows (with and without microgeneration integration)
  - Estimate the amount of avoided CO_2 emissions
  - Evaluate benefits from investment deferral

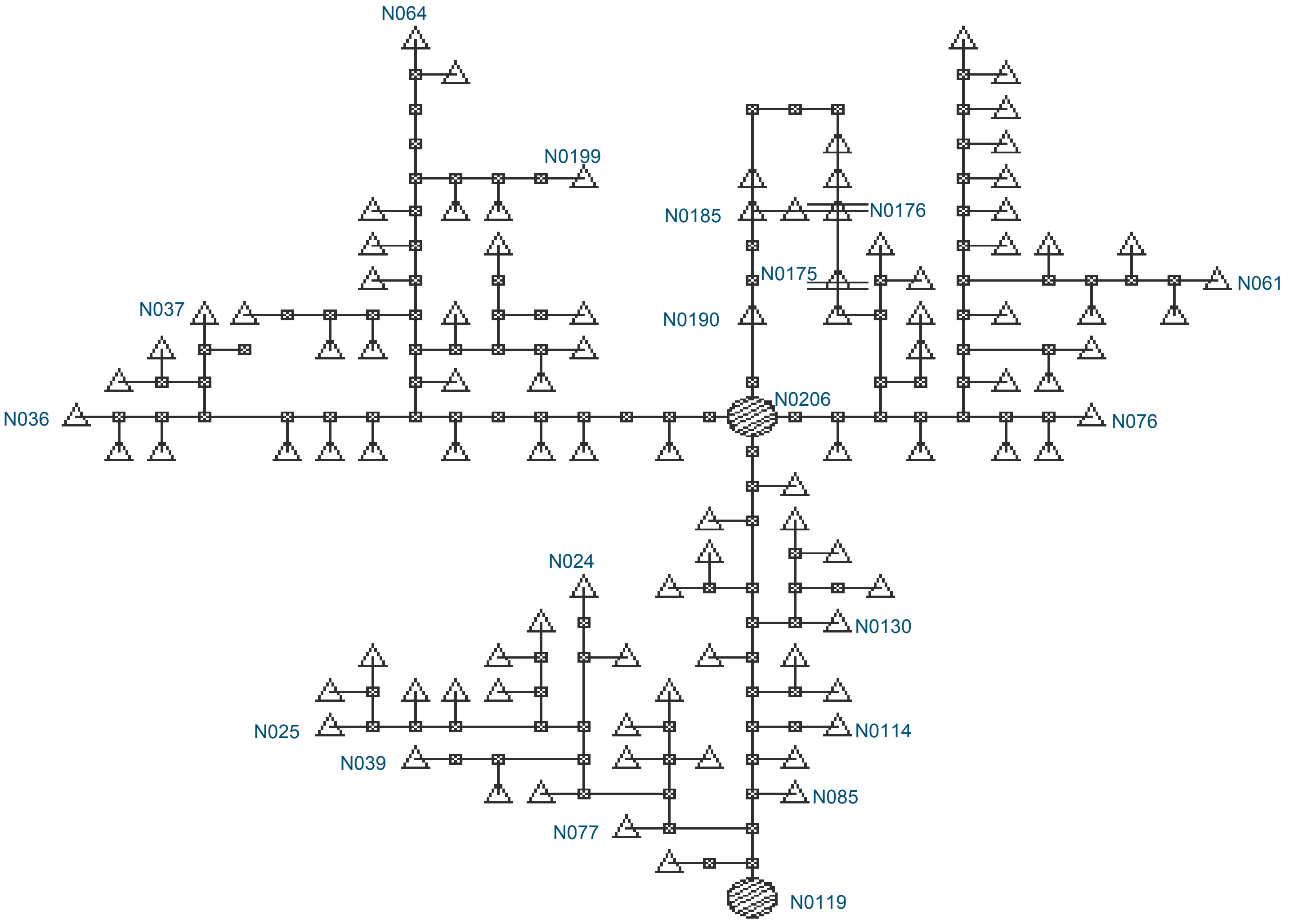
For 1 year

For 25 years

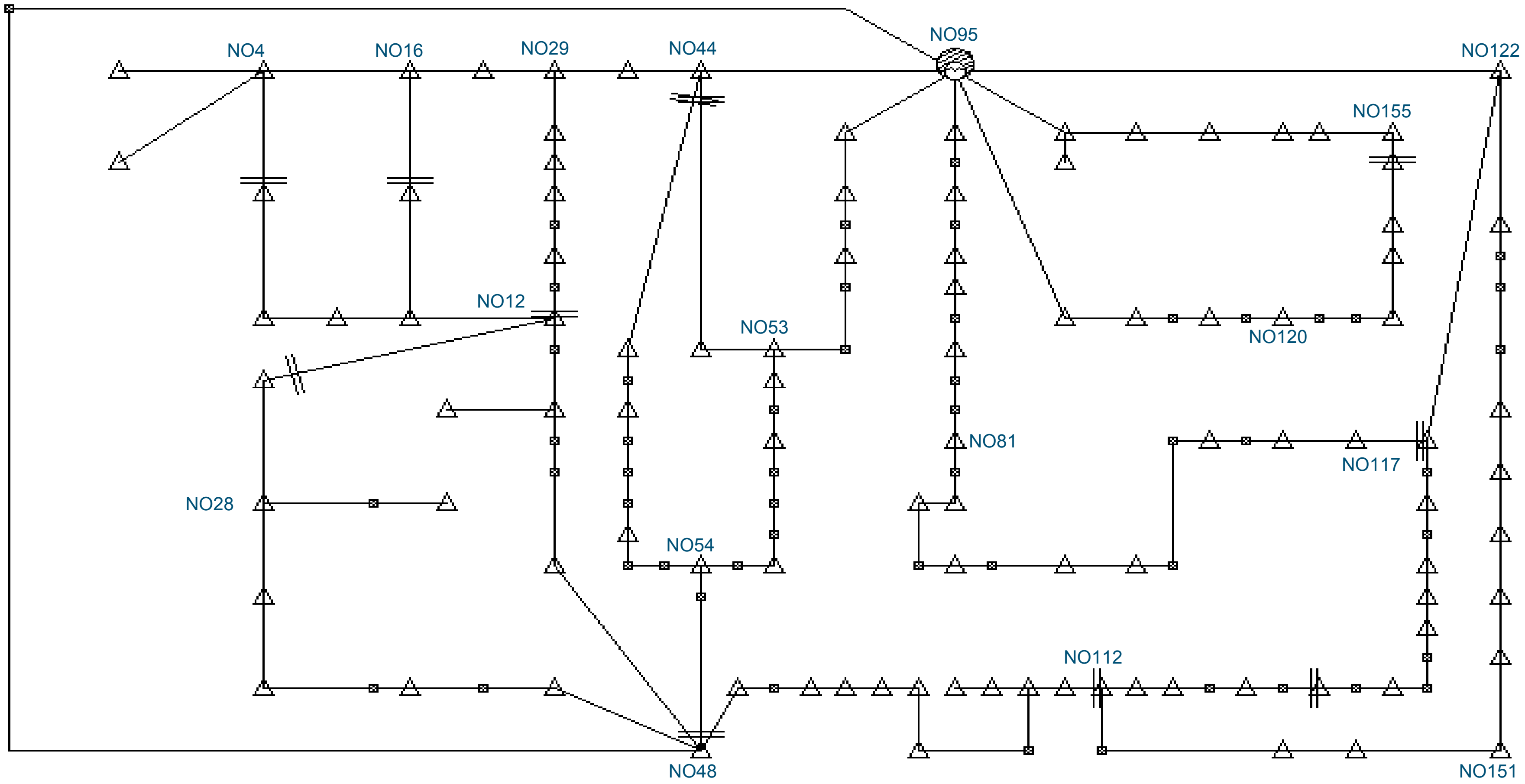
Typical High Voltage Network



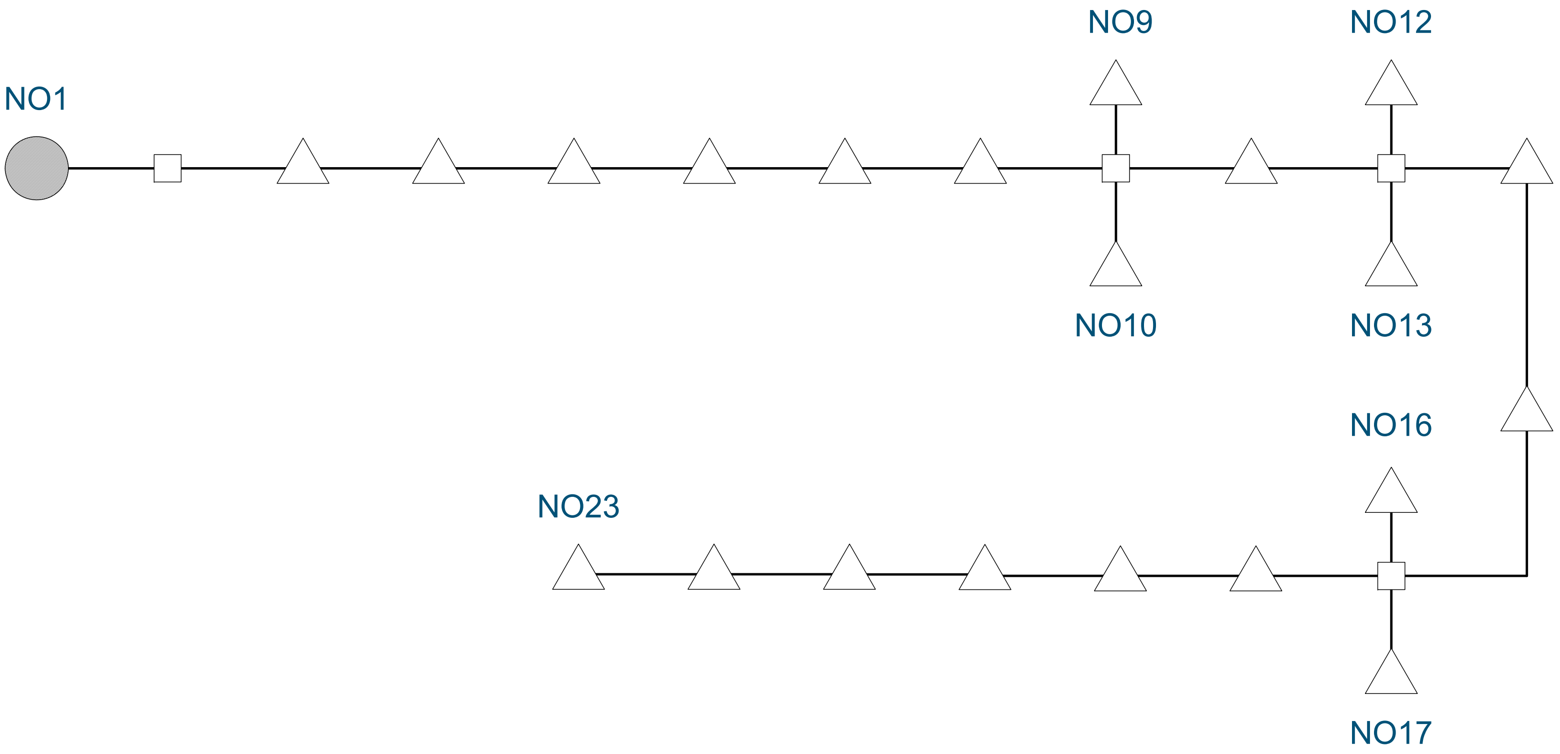
Typical Rural Medium Voltage Network



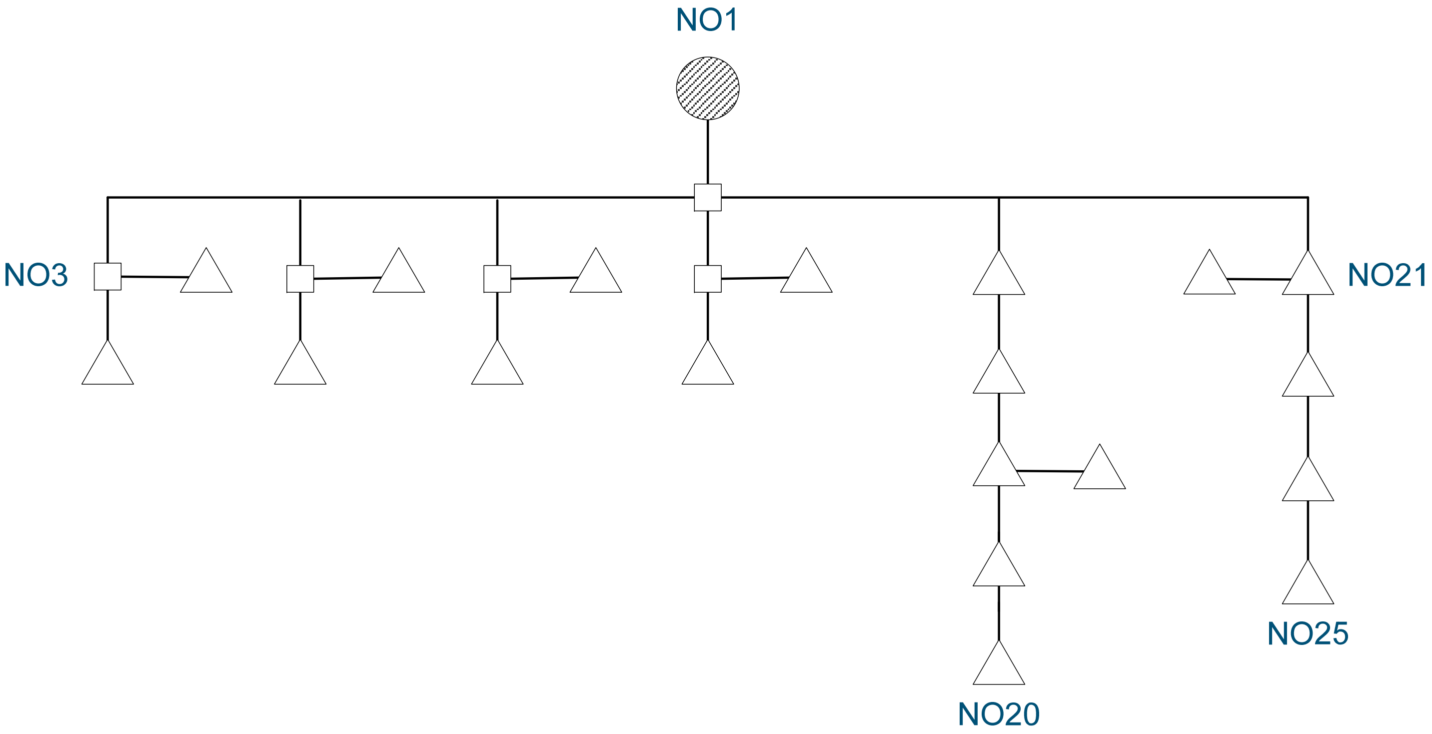
Typical Urban Medium Voltage Network



Typical Rural Low Voltage Network



Typical Urban Low Voltage Network



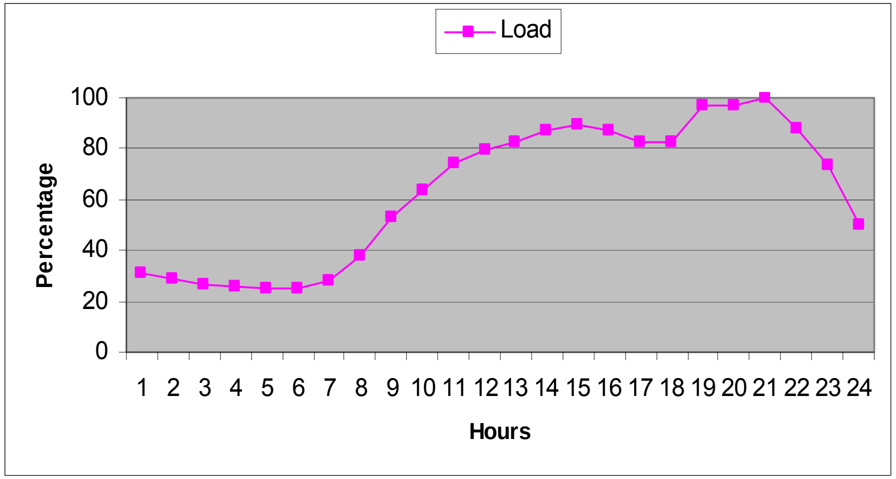
Defining Scenarios…

- Scenarios for Load
  - 24h Daily diagrams for Summer/Spring and Winter/Autumn time
- Scenarios for Generation (considering 10%, 20% and 30% of microgeneration penetration)
  - 24h Daily diagrams for Summer/Spring and Winter/Autumn time, considering different microgeneration technologies:
    - Micro-Wind generation
    - Micro-PV generation
    - Micro-CHP generation
    - Micro-Hydro generation

Penetration level (%)= µGeneration installed capacity *100/peak load

Load Scenarios

- Example: Aggregated curve considering a mix of residential and commercial consumers



Typical Aggregated Daily Load Diagram for Portugal (% of peak value)

Generation Scenarios

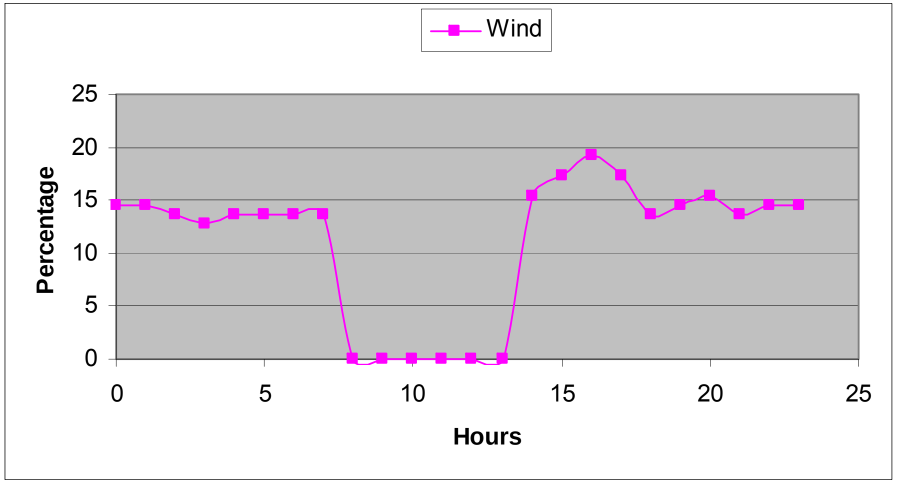
- Main Assumptions
  - No DG is considered to be connected directly to the MV and HV level
  - The LV networks connected to the MV level are all considered to be microgrids
  - It is considered that 60% of the MV networks connected to the HV level are Urban and 40% are Rural type
- The inclusion of microgeneration is simulated by reducing the load at all load nodes according to the percentage of the peak load

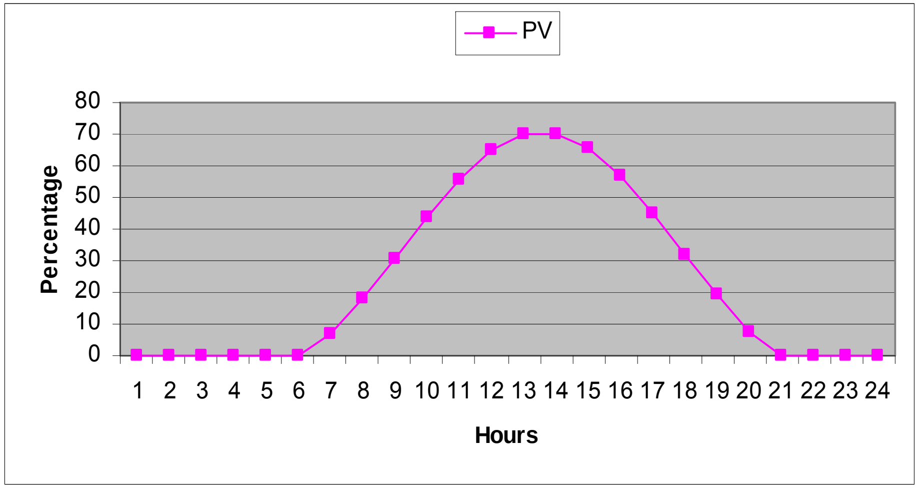
Generation Scenarios

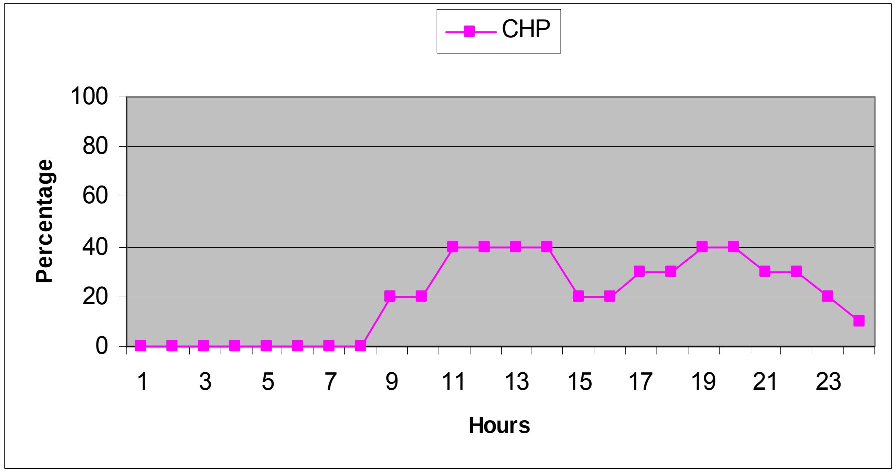
- Generation Percentages for each Scenario per Technology

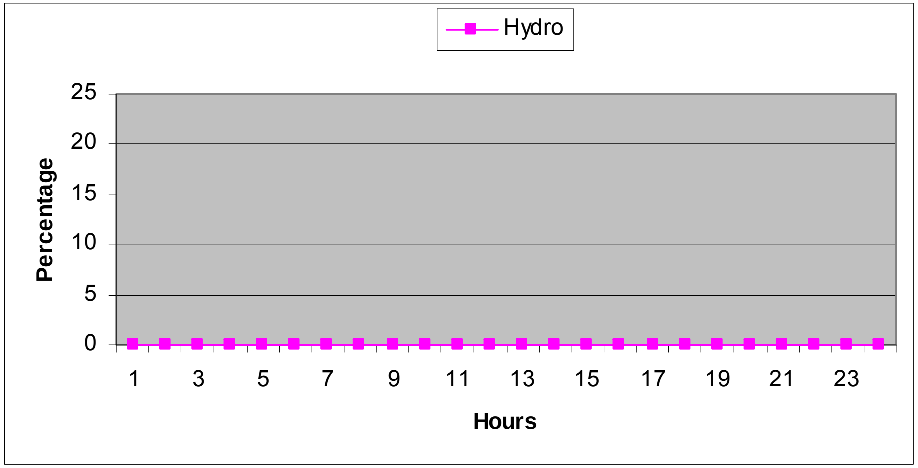
Network	Generation Technology	Percentage per Technology
HV	CHP	42,00%
	Hydro	16,00%
	PV	26,00%
	Wind	16,00%
RMV	CHP	
	Hydro	40,00%
	PV	20,00%
	Wind	40,00%
UMV	CHP	70,00%
	Hydro	
	PV	30,00%
	Wind	
RLV	CHP	
	Hydro	40,00%
	PV	20,00%
	Wind	40,00%
ULV	CHP	70,00%
	Hydro	
	PV	30,00%
	Wind	

Generation Scenarios – Summer/Spring

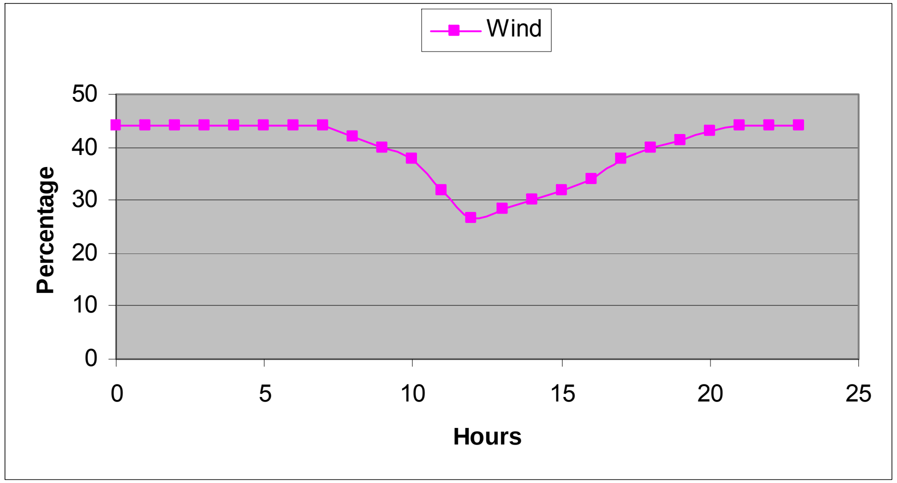


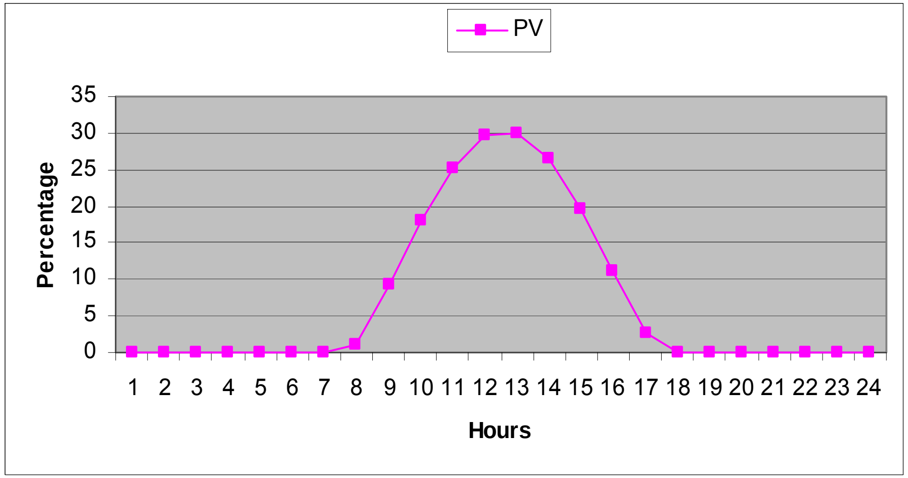


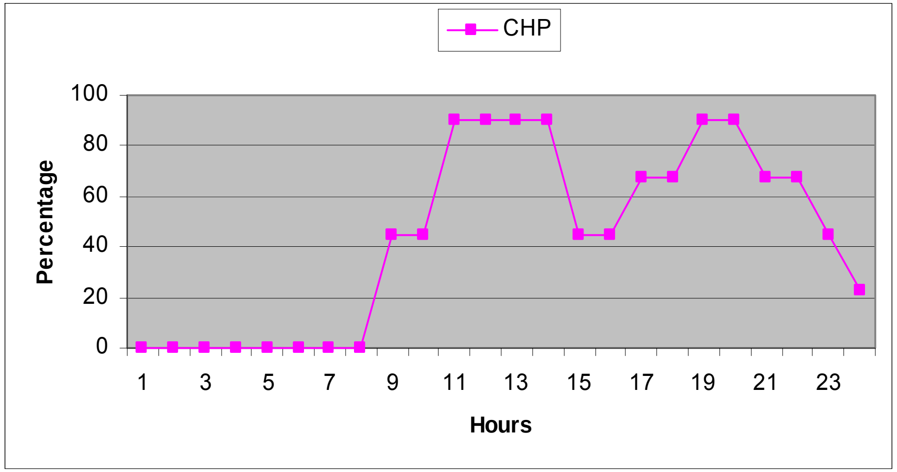


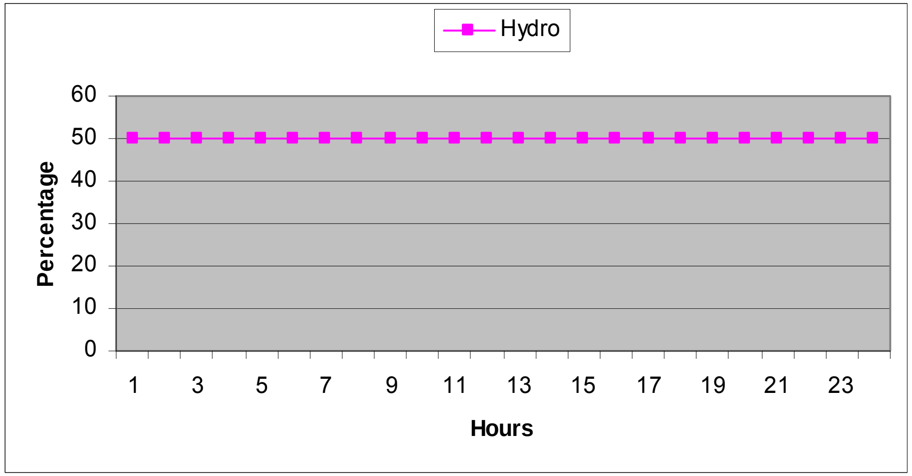


Generation Scenarios – Winter/Autumn









Analysis Procedure

- Loss reduction
  - Distribution System Losses (2005) → 3437 GWh

Distribution Networks	Percentage of the Total (%)
Rural LV	24,0
Urban LV	36,0
Rural MV	13,6
Urban MV	20,4
HV	6,0
Total	100,0

Distribution Networks Percentage per Voltage Level

- Environmental benefits (reduction of CO_2 emissions)
  - Estimate the amount of CO_2 emissions that can be avoided due to loss reduction (370 $tonCO_2/GWh$ – ERSE reference value for 2005)

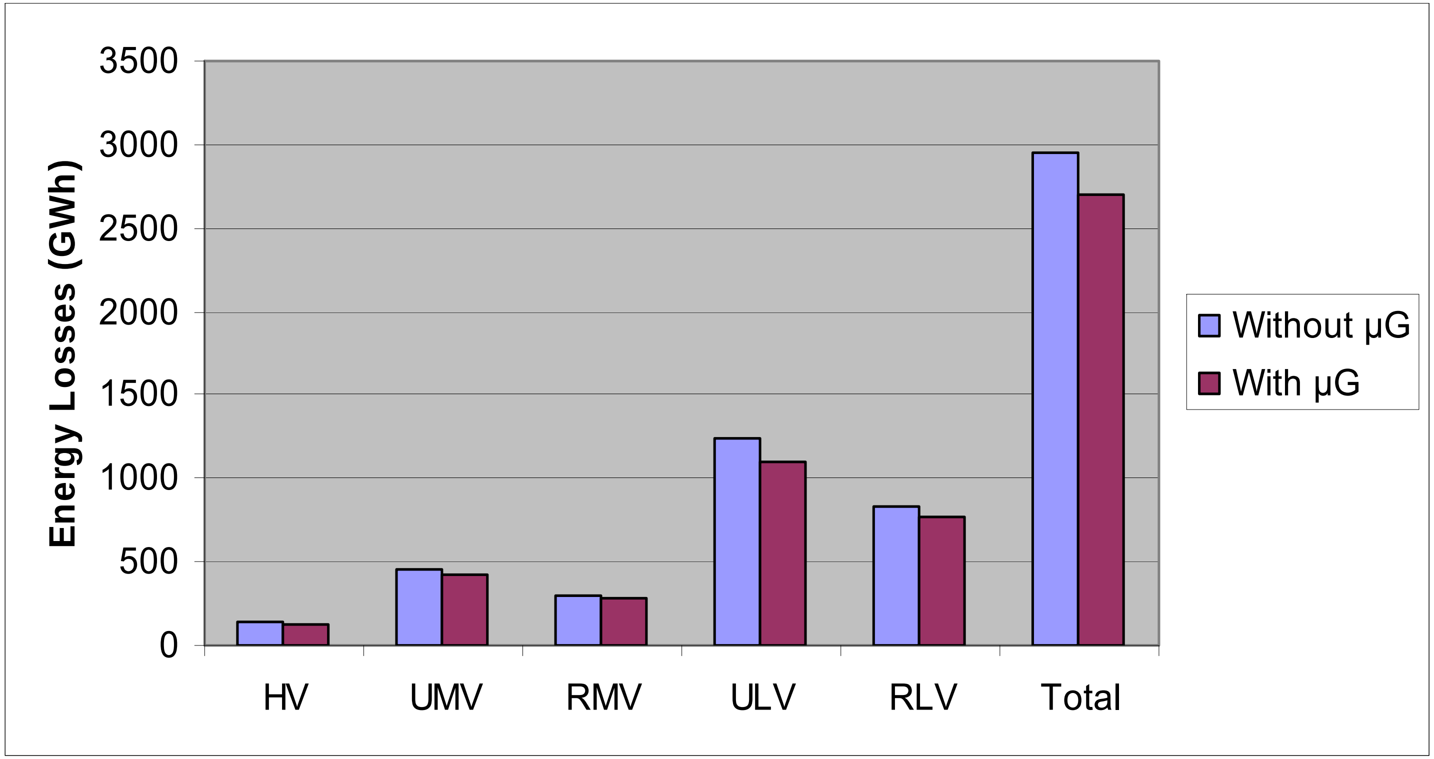
Analysis Procedure

- Investment deferral
  - May be estimated in 2 different ways, depending on the type of network to analyze (urban or a rural):
    - Investment deferral in urban networks is assessed by evaluating the reduction of line loading considering microgeneration integration
    - For the case of rural networks, the benefits regarding investment deferral are evaluated in terms of the voltage drop reduction across a feeder due to microgeneration integration

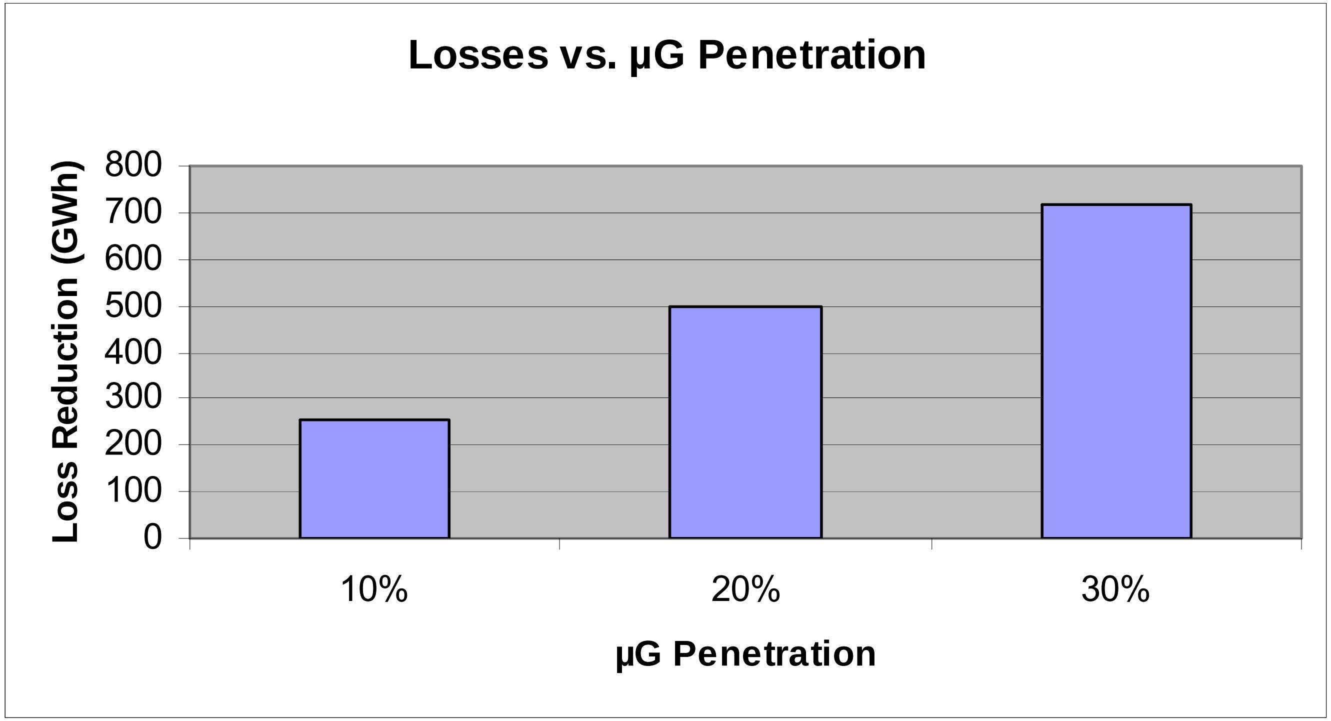
	Reinforcement Investments 2005 (10^6 euros)
HV/MV Substation	30,06
HV Aerial Line	25,29
HV Underground Cables	5,09
MV/MV Substation	1,15
MV Aerial Line	23,27
MV Underground Cables	12,71
Transformer Stations	8,12
LV Aerial Line	9,57
LV Underground Cables	4,04
Total	**94,50**

Results

- 10% Microgeneration Penetration



Results


Losses vs. µG Penetration
Loss Reduction (GWh)
800
700
600
500
400
300
200
100
0
10%
20%
30%
µG Penetration

Results

- 10% Microgeneration Penetration

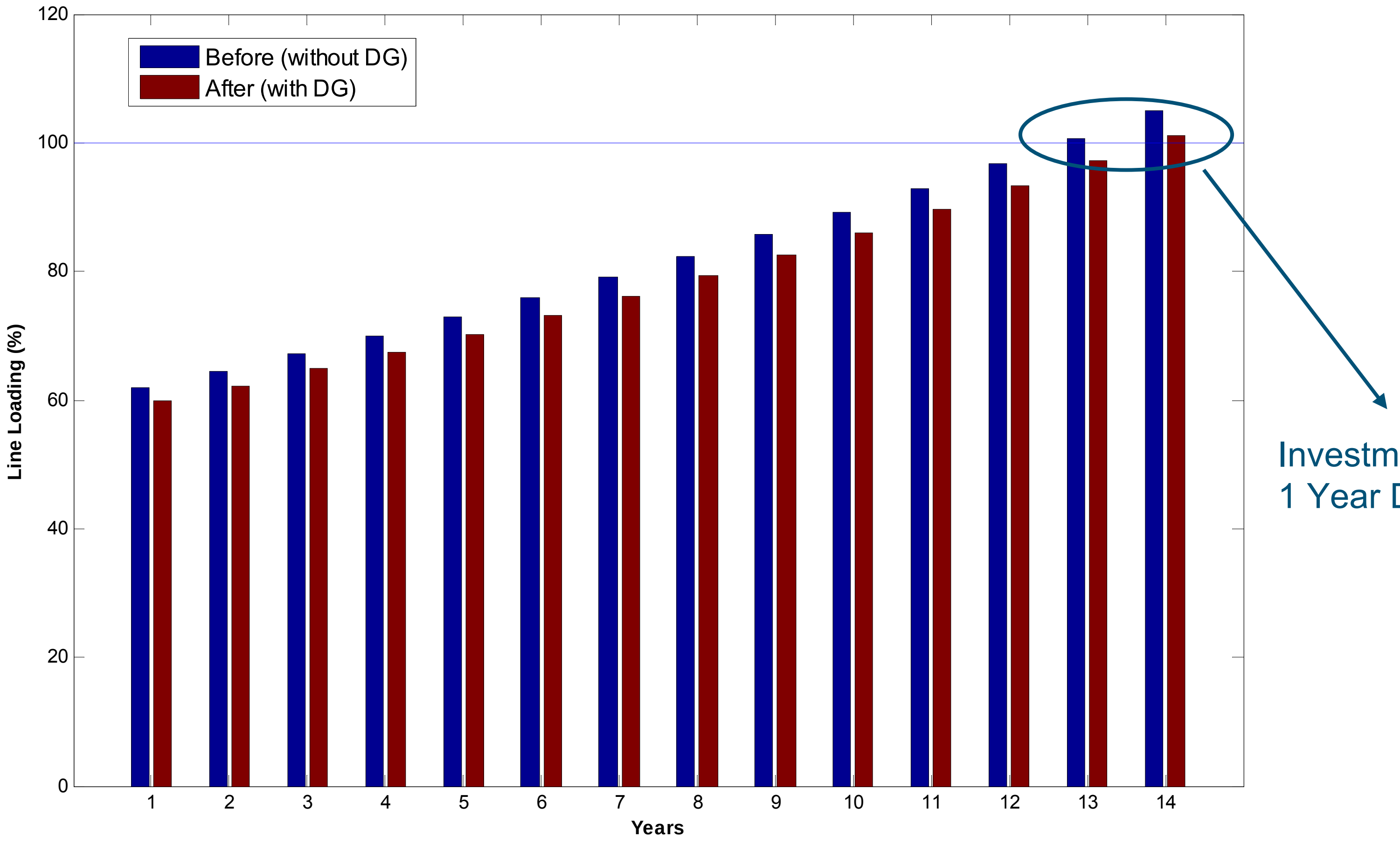
	Energy Loss Reduction (%)	Energy Loss per Network Type (without μG) (GWh)	Energy Loss per Network Type (with μG) (GWh)	Diferential
HV	5,15	134	127	7
UMV	7,35	456	422	33
RMV	4,79	304	289	15
ULV	11,35	1237	1097	140
RLV	7,55	825	763	62
Total	8,72	2956	2698	258
	Loss Rate (%)	7,0	6,4	0,6
	CO_2 (ton)	1093653	998330	95324

Considering:
370 tonCO_2/GWh
(ERSE reference value)

0.05 €/kWh
(average energy cost) ⇒ 12,9 M€ avoided costs in losses

Results

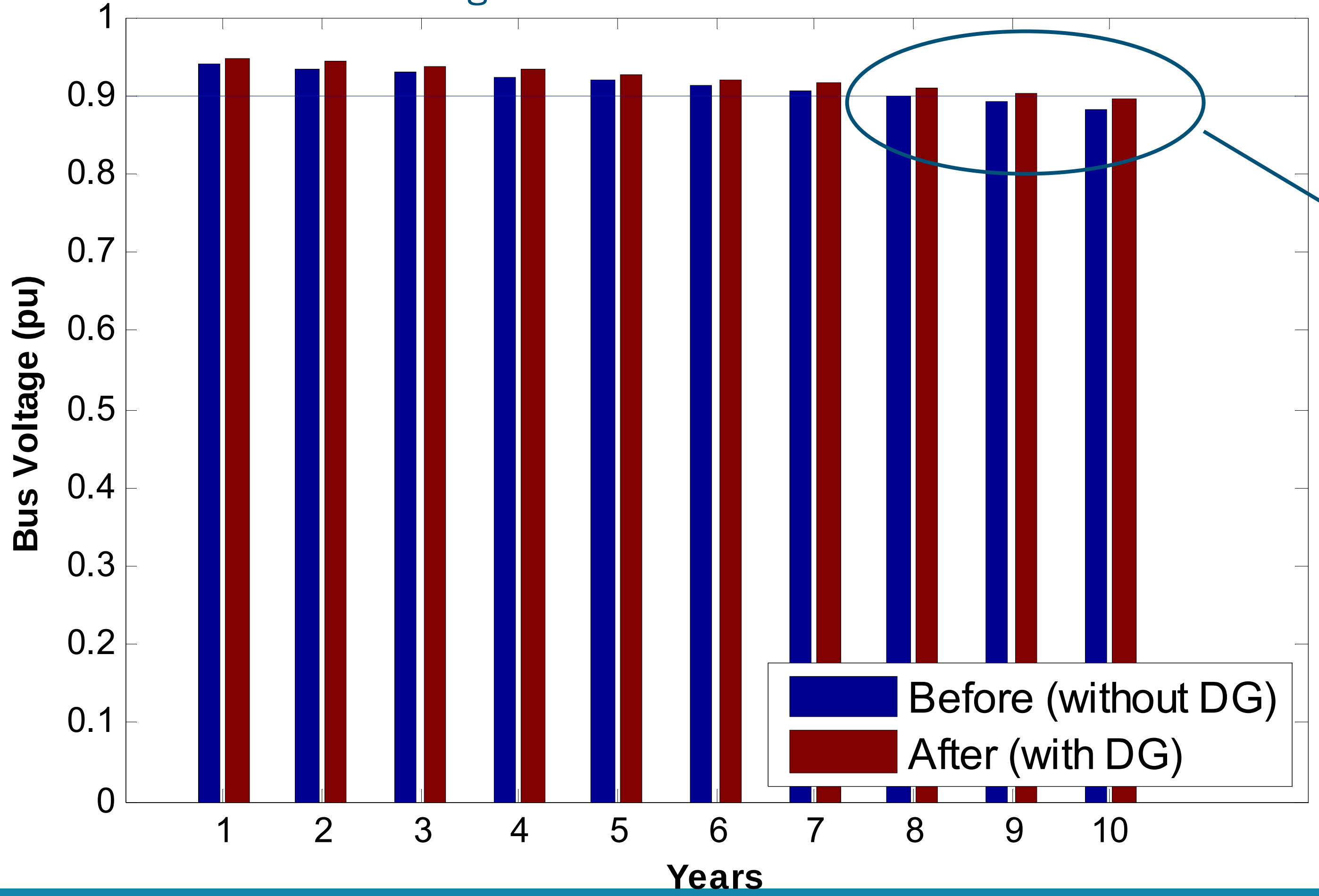
- 10% Microgeneration Penetration: UMV Network – Winter/Autumn
  - Branch with more loading: evolution in time



Investment
1 Year Delayed

Results

- 30% Microgeneration Penetration: RMV Network – Winter/Autumn
  - Worst Bus Voltage evolution in time



Investment
2 Years Delayed

Results

- 10% Microgeneration Penetration

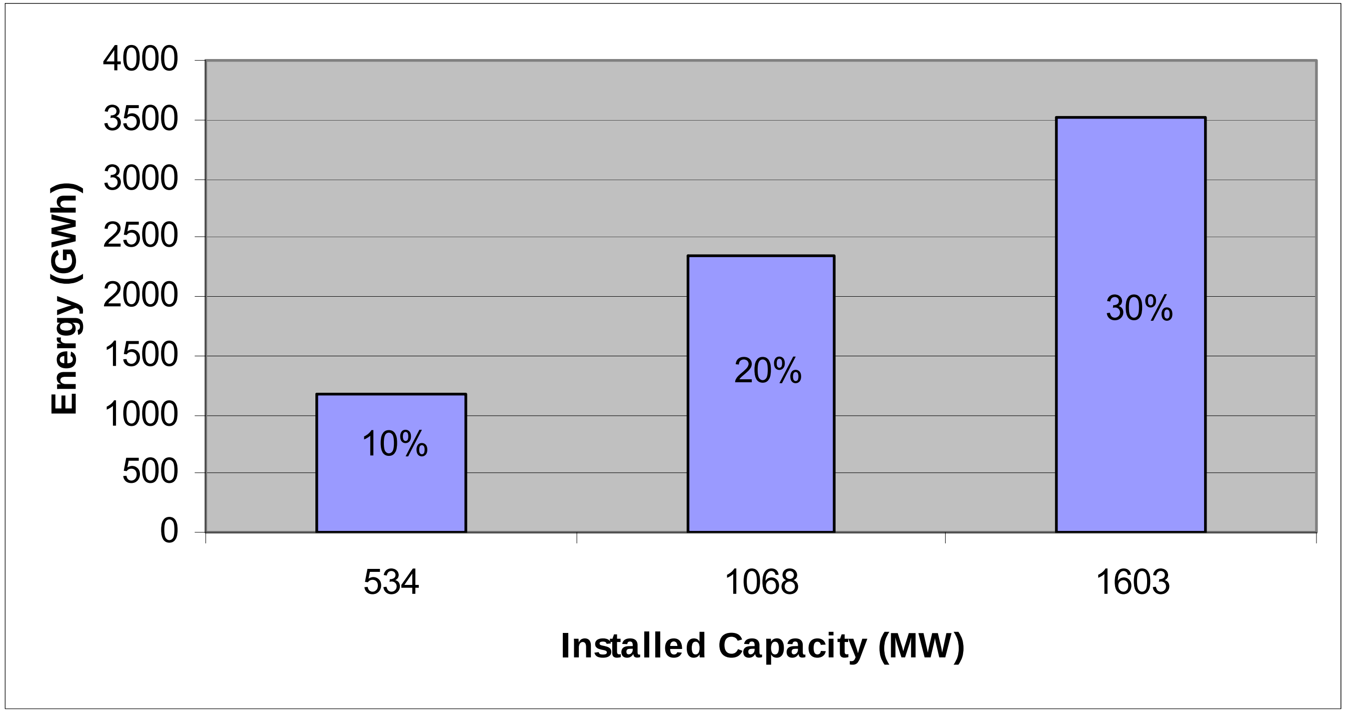
Year	Energy Loss Reduction (10^6 euros)	Line Loading Reduction Year 1 (10^6 euros)	Line Loading Reduction (10^6 euros)	
1	12,882	0,207		
2	12,924		0,000	
3	12,967		0,199	
4	13,010		0,000	
5	13,053		0,191	
6	13,096		0,000	
7	13,140		0,184	
8	13,183		0,000	
9	13,227		0,177	
10	13,271		0,000	
11	13,315		0,171	
12	13,359		0,000	
13	13,403		0,164	
14	13,448		0,000	
15	13,492		0,158	
16	13,537		0,000	
17	13,582		0,152	
18	13,627		0,000	
19	13,672		0,147	
20	13,718		0,000	
21	13,763		0,141	
22	13,809		0,000	
23	13,854		0,136	
24	13,900		0,000	
25	13,946		0,131	**Total**
Total	335,181	0,207	1,953	**337,3403**

$$\sum_{i=1}^{n}\left[C_0\cdot\frac{(1+t_c)^{i-1}}{(1+t_a)^{i-1}}+\frac{I_{i-1}\cdot t_a}{(1+t_a)^{i-1}}\right]$$

Savings resulting from the reduction in the average annual energy losses for a time span of 25 years, at the present time

Avoided interests due to postponing for 25 years the line and transformer investments

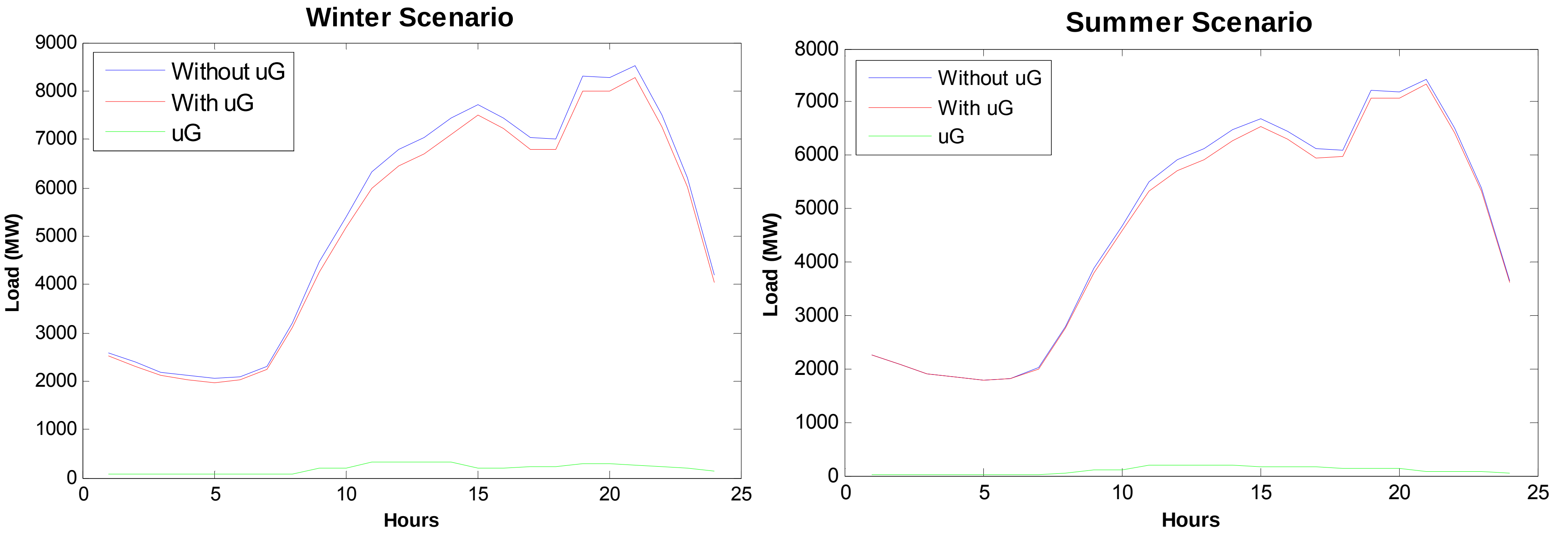
Microgeneration Installed Capacity and Total Energy Generation



Largely dependent on the mix of microsources

Daily Load Diagram

- 10% Microgeneration Penetration



Maximum μG contribution: 337 MW

μG contribution at peak load: 248 MW

Maximum μG contribution: 204 MW

μG contribution at peak load: 86 MW

Avoided energy generation : 1272 GWh (in year 2005)

Conclusions - Benefits

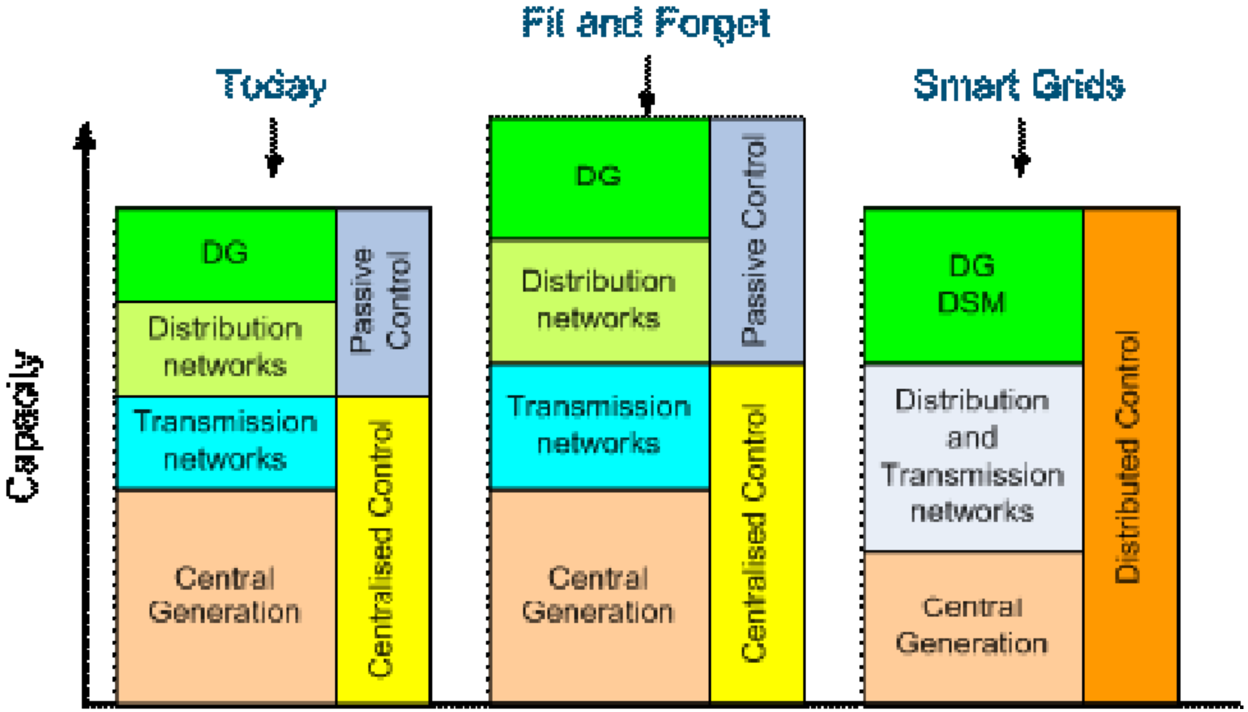
- Large technical, economic and environmental benefits can be achieved by using microgeneration:
  - Considerable amount of loss network reduction;
  - Better voltage profiles;
  - Reliability improvements;
  - Increased economic performance of the distribution activity
    - investment deferral network reinforcement costs;
    - avoided costs in network losses.
  - Avoided CO2 emissions

Specific and fair new remuneration schemes must be identified

Beneficiaries: Microgenerators, consumers, DSOs, society

Conclusions - Benefits

- Consequences of the SmartGrid concept



Conclusions - Benefits

- Society benefits (less tangible benefits related to energy policy):
  - increased security of power systems,
  - diversification of primary energy sources,
  - reduction on energy external dependence),
  - potential economic benefits (new economic activities, innovation).

How to share these benefits?

The microgenerator should recover its cost and should take a part of these benefits

Conclusions – Next steps

- Adjustments in the regulatory framework are needed
- Two approaches should be exploited:
  - For DG units
    - Remuneration of ancillary services to μG
    - Additional incentives for better located μG units
      - Nodal cost prices approaches can be used (active and reactive) → requires
  - For DSO
    - Incentives to accept and manage μG (accept additional monitoring and control costs developed by DSO), since general loss reduction can be achieved
      - Target values for the losses should be more ambitious, with stronger incentives (within the normal regulatory schemes). Ex: Ofgem.
      - Again the nodal cost mechanism can be used
    - Incentives to accept DG, since deferral in reinforcement investments can be obtained