Overview of Microgrids, Problems and Solutions

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"Distributed Generation, Grid and Micro Grid Problems", Bilbao, 19th October 2004

Topics

- Introduction
- Definition
- Technical, Economic and Environmental Benefits of MicroGrids
- Conceptual design of MicroGrids
- Integration requirements and device-network interfaces
- Market and regulatory frameworks for MicroGrids
- Modelling and simulation of MicroGrids
- The MicroGrids Project
- Conclusions

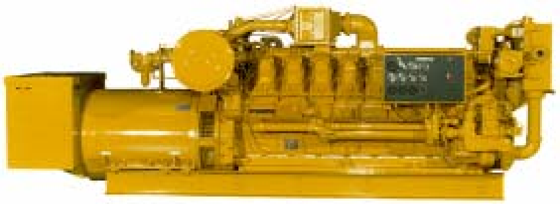
Introduction

- In the last 20 years power systems witnessed important changes:
  - Centralized paradigm versus more decentralized and market driven approaches;
  - Legal and regulatory changes;
    - Vertical and horizontal changes;
    - New tariff systems;
  - Large technical advances (communications and computation);
  - Larger environmental concerns;
  - New generation technologies

Distributed Generation Technologies

Examples

Advanced Turbines



Reciprocating Engines

Fuel Cells

Photovoltaics

Wind

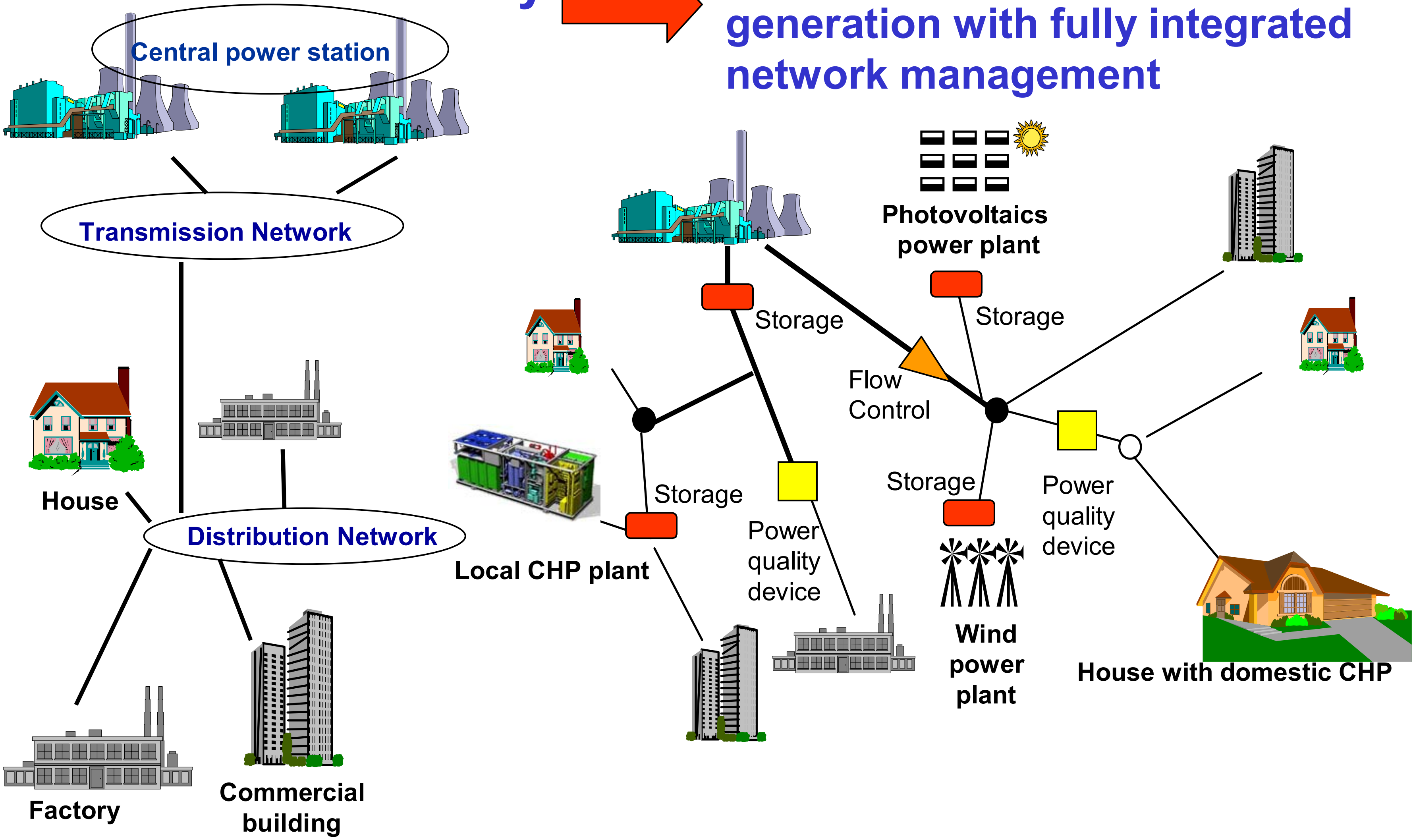
Thermally Activated Technologies

Microturbines

The vision.....

Yesterday

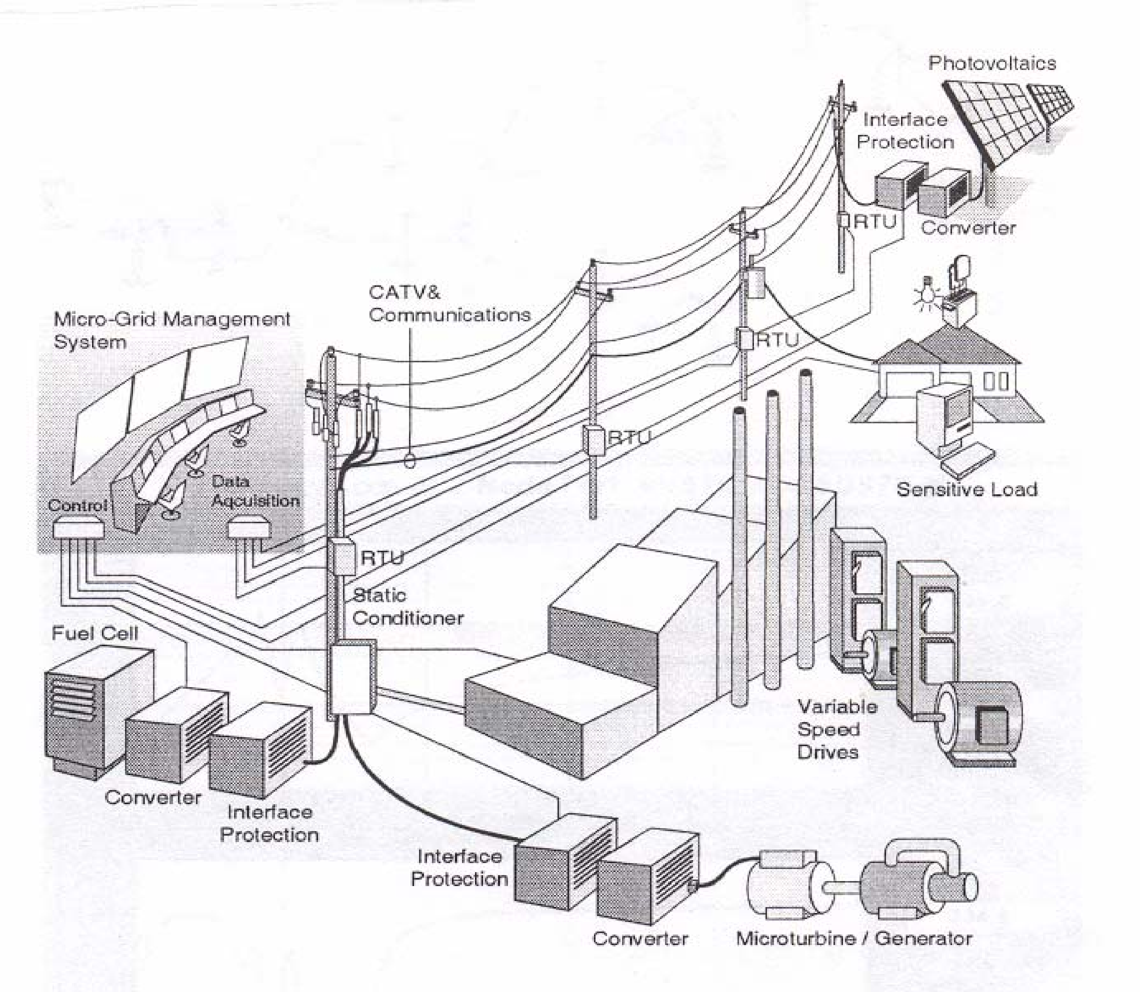
Tomorrow: distributed/ on-site generation with fully integrated network management



What are MICROGRIDS?

Interconnection of small, modular generation to low voltage distribution systems can form a new type of power system, **the MicroGrid**.

MicroGrids can be operated connected to the main power network or autonomously, similar to power systems of physical islands, in a **controlled, coordinated way** .

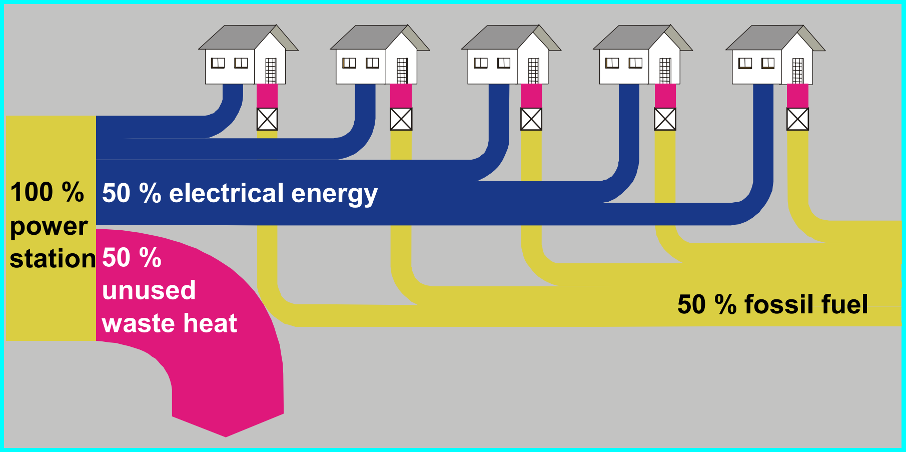


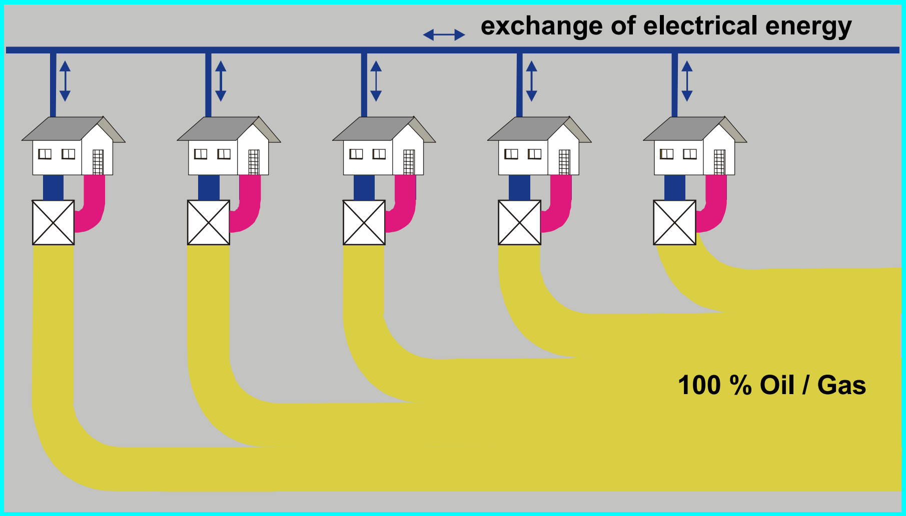
Technical, economic and environmental benefits

- Energy efficiency
- Minimisation of the overall energy consumption
- Improved environmental impact
- Improvement of energy system reliability and resilience
- Network benefits
- Cost efficient electricity infrastructure replacement strategies
- *Cost benefit assessment*

Energy Efficiency - Combined Heat and Power

Prof. Dr. J. Schmid





Up to now:

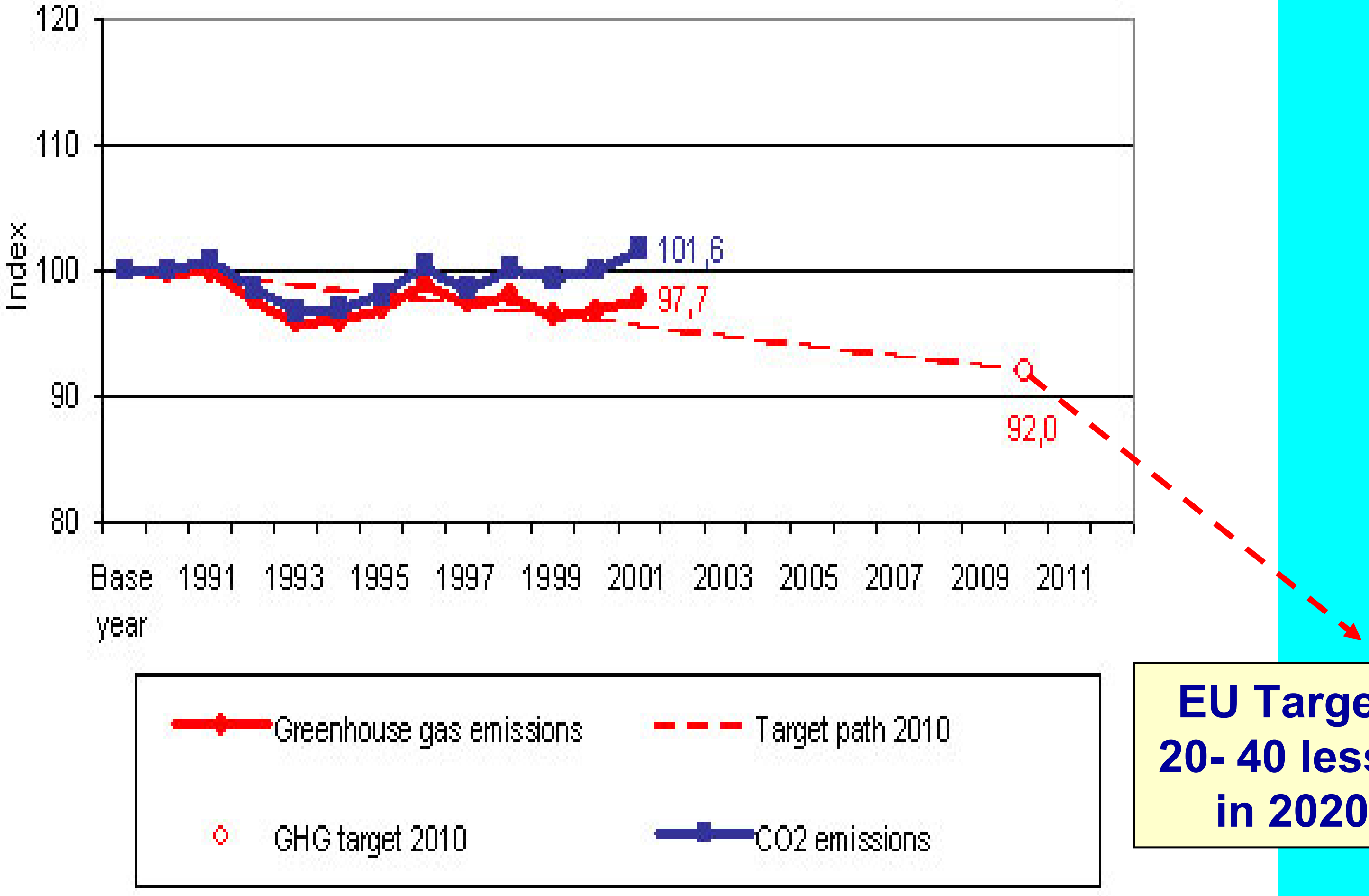
- Central power stations
- Decentral heat production

In Future:

- Decentral combined heat and power

⇒ 1/3 less consumption of fossil sources of energy

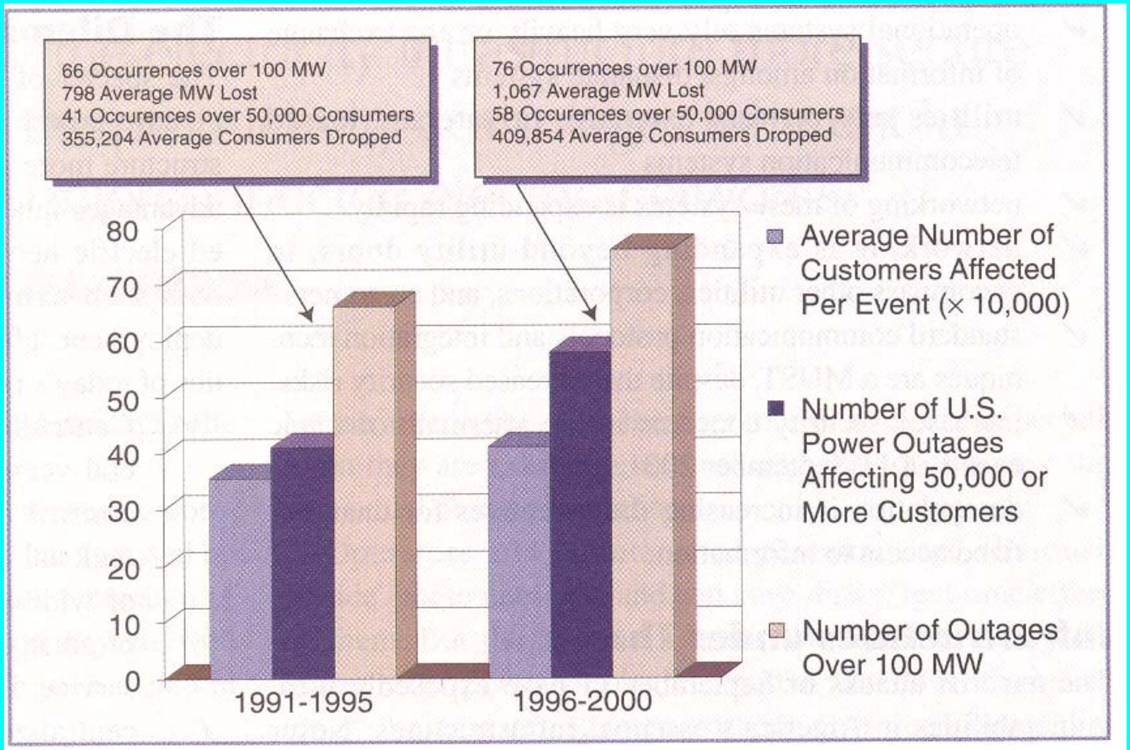
Towards Kyoto or rather away from it?



EU Target:-
20- 40 less in
in 2020!

Manuel Sanchez

Increasing frequency and size of US power outages 100 MW or more (1991-1995 vs. 1996-2000), affecting 50,000 or more consumers per event.



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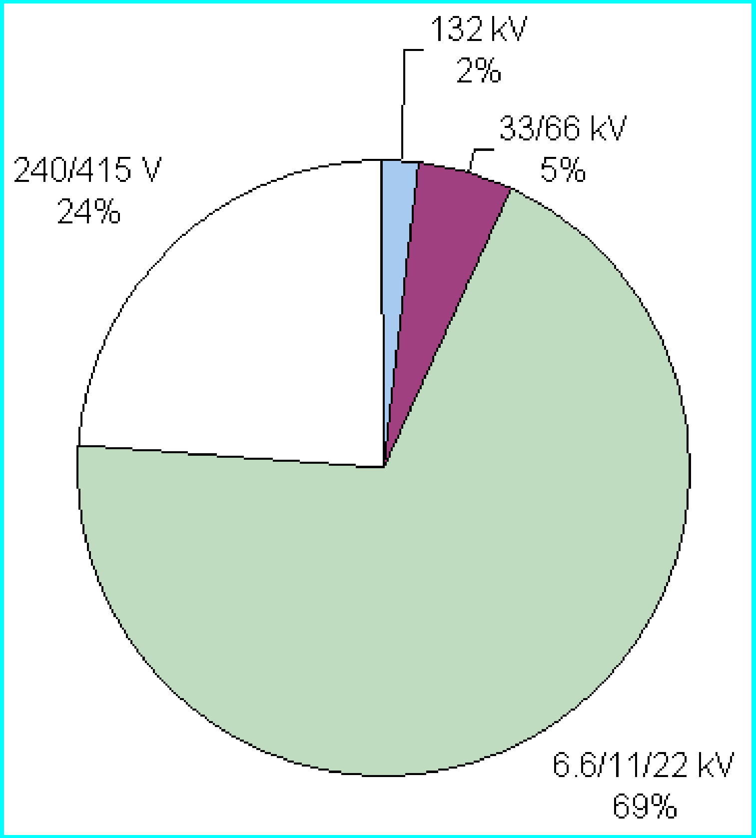
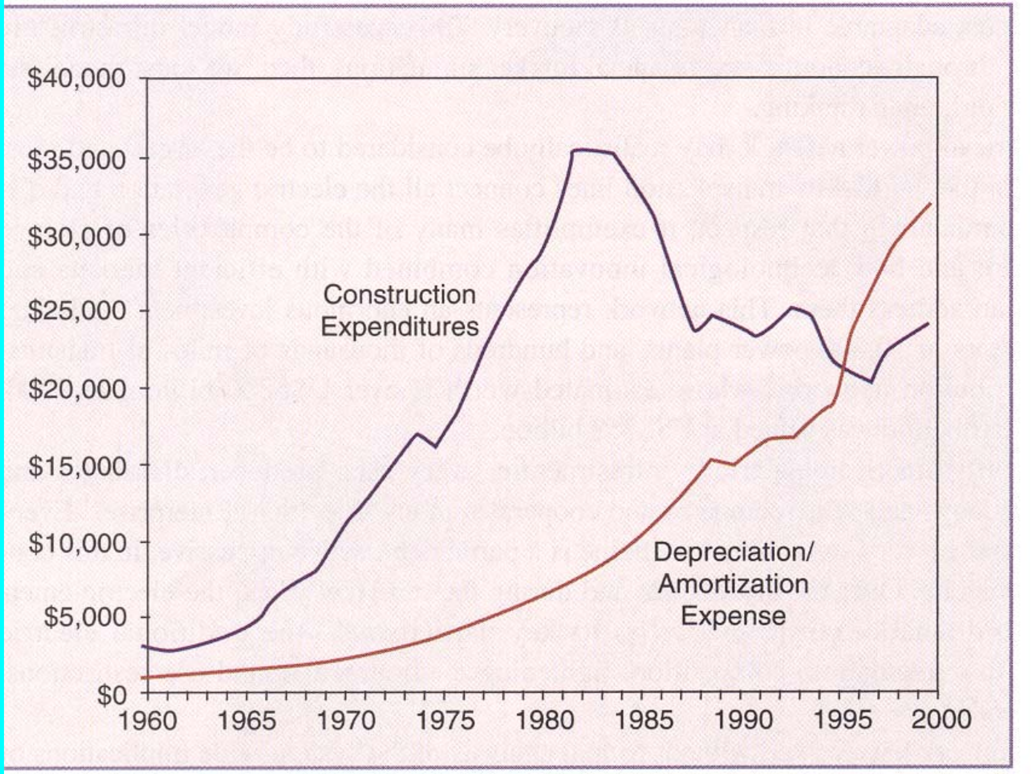
M.Amin – Balancing Market Priorities with Security Issues, IEEE Power&Energy, Vol. 2, Nr. 4, July/August 2004, data NERC's disturbance analysis working group database)

Improvement of Reliability

Distribution of CMLs



Utility Constructions: “Harvesting the farm far more rapidly than planting new seeds”

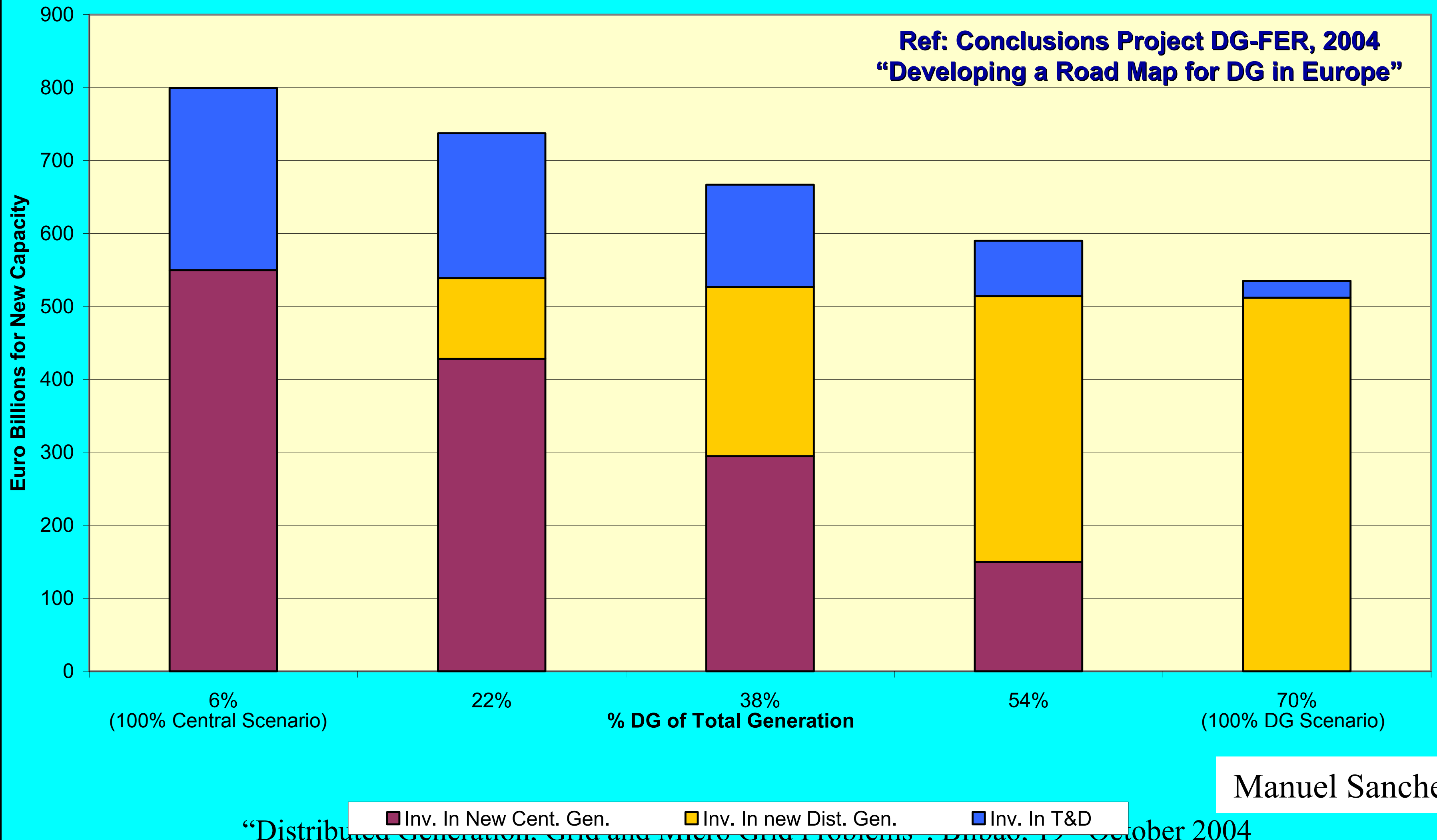


Since 1995 to the present, the amortization/depreciation rate

- exceeds utility construction expenditures

M.Amin – Balancing Market Priorities with Security Issues, IEEE Power&Energy, Vol. 2, Nr. 4, July/August 2004, data by EEI and graph by EPRI)

Capital Cost to Supply 2020 Electric Load Growth



Ref: Conclusions Project DG-FER, 2004
“Developing a Road Map for DG in Europe”

Manuel Sanchez

Technical Challenges for Microgrids

- Relatively large imbalances between load and generation to be managed (significant load participation required, need for new technologies, review of the boundaries of microgrids)
- Specific network characteristics (strong interaction between active and reactive power, control and market implications)
- Small size (challenging management)
- Use of different generation technologies (prime movers)
- Presence of power electronic interfaces
- Protection and Safety

Market and Regulatory Challenges

- coordinated but decentralised energy trading and management
- market mechanisms to ensure efficient, fair and secure supply and demand balancing
- development of price-based energy and ancillary services arrangements for congestion management
- secure and open access to the network and efficient allocation of network costs
- alternative ownership structures, energy service providers
- new roles and responsibilities of supply company, distribution company, and consumer/customer

MICROGRIDS Project

“Large Scale Integration of Micro-Generation to Low Voltage Grids

Contract : ENK5-CT-2002-00610

14 PARTNERS,
7 COUNTRIES

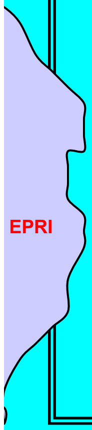
GREAT BRITAIN
- **UMIST**
- **URENCO**

PORTUGAL
- **EDP**
- **INESC**

SPAIN
- **LABEIN**

NETHERLANDS
- **EMforce**

USA
- **EPRI**



GREECE
- **GERMANOS**
- **ICCS/NTUA**
- **PPC /NAMD&RESD**

GERMANY
- **SMA**
- **ISET**

FRANCE
- **EDF**
- **Ecole des Mines de Paris/ARMINES**
- **CENERG**

http://microgrids.power.ece.ntua.gr

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The MicroGrids Project

R&D Objectives:

- Contribute to increase the share of renewables and to reduce GHG emissions;
- Study the operation of MicroGrids in normal and islanding conditions;
- Optimize the operation of local generation sources;
- Develop and demonstrate control strategies to ensure efficient, reliable and economic operation;
- Simulate and demonstrate a MicroGrid in lab conditions;
- Define protection and grounding schemes;
- Define communication infrastructure and protocols;
- Identify legal, administrative and regulatory barriers and propose measures to eliminate them;

MICROGRIDS - 9 Workpackages

- Investigation of Regulatory, Commercial, Economic and Environmental Issues
- Development of Steady State and Dynamic Simulation Tools
- Development of Local Micro Source Controllers
- Development of Micro Grid Central Controller
- Development of Emergency Functions
- Investigation of Safety and Protection
- Investigation of Telecommunication Infrastructures and Communication Protocols
- Development of Laboratory MicroGrids
- Evaluation of the system performance on study case networks

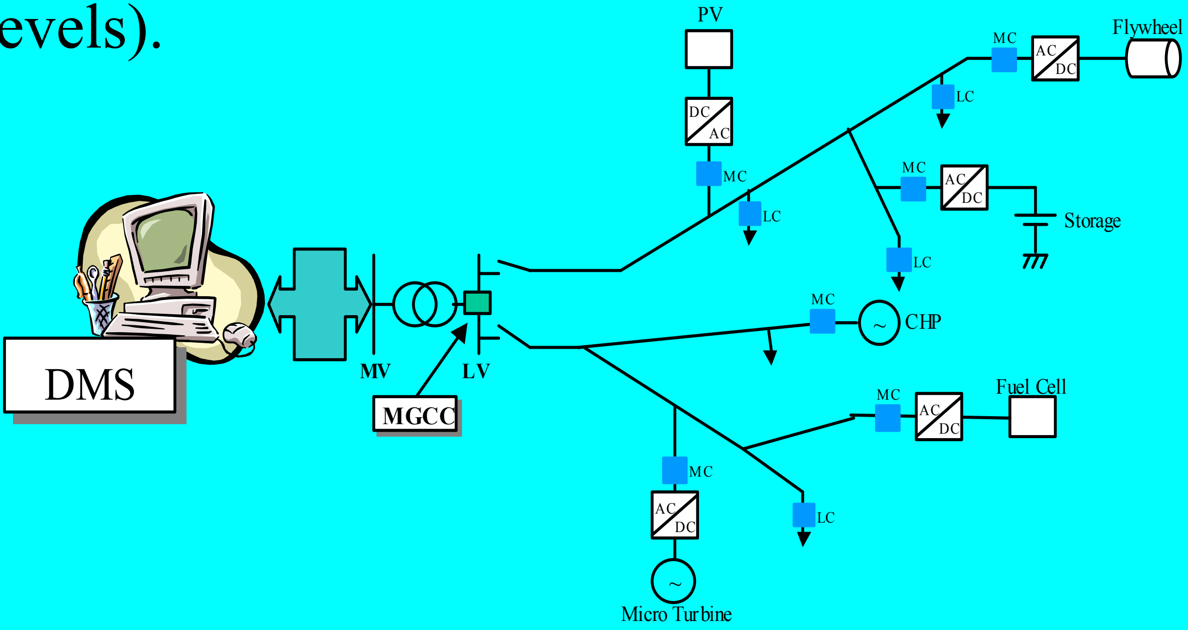
MicroGrids Highlights

- Islanding and interconnected operation philosophy
- Control philosophies (hierarchical vs. distributed)
- Energy management within and outside of the distributed power system
- Device and interface response and intelligence requirements
- Permissible expenditure and quantification of reliability benefits
- protection options for networks of variable configurations
- Steady State and Dynamic Analysis Tools

MicroGrids – Hierarchical Control

MicroGrid Central Controller (MGCC) promotes technical and economical operation, provides set points to LC and MC; Interface with loads and micro sources and **DMS;**

MC and LC Controllers: interfaces to control interruptible loads and micro sources (active and reactive generation levels).



Interconnected Operation

- MicroGrids can operate:
  - Normal Interconnected Mode :
    - Connection with the main MV grid;
    - Supply, at least partially, the loads or injecting in the MV grid;
    - In this case, the MGCC:
      - Interfaces with MC, LC and DMS;
      - Perform studies (forecasting, economic scheduling, DSM functions,…);

Islanding Operation

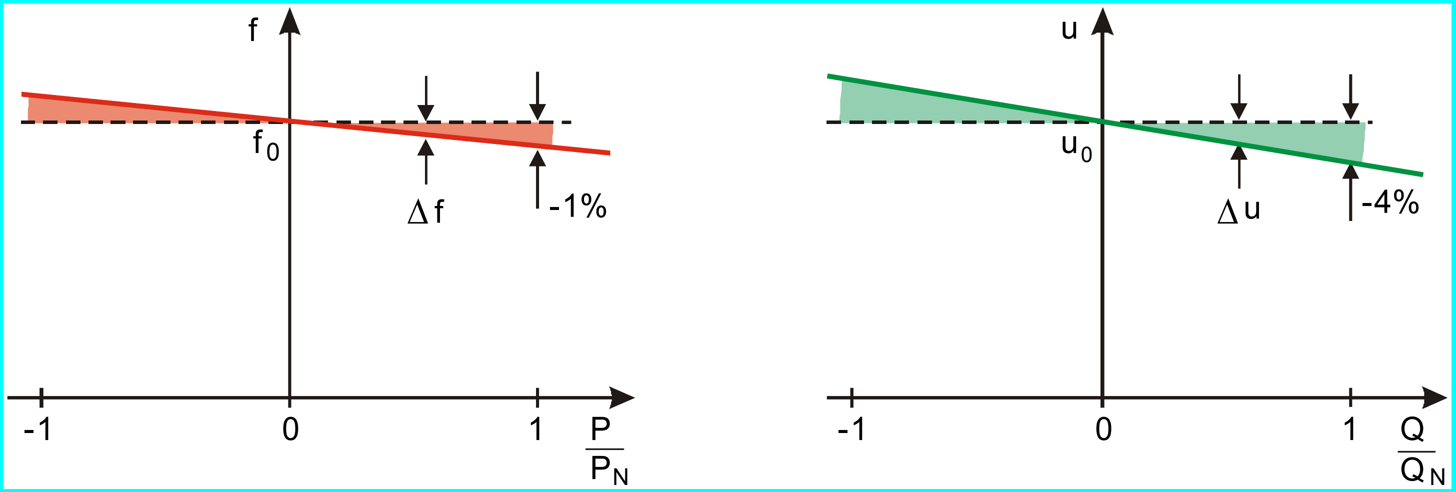
- MicroGrids can operate:
  - Island Mode :
    - In case of failure of the MV grid;
    - Possible operation in an isolated mode as in physical islands;
    - In this case, the MGCC:
      - Changes the output control of generators from a dispatch power mode to a frequency mode;
      - Primary control – MC and LC;
      - Secondary control – MGCC (storage devices, load shedding,…);
      - Eventually, triggers a black start function.

Improved reliability and resilience

Integration requirements and device-network interfaces

- operation as the “good” and “model citizen”
- seamless transition between interconnected/islanding mode
- resilience under changing conditions
- operation fault level management and protection
- recovery from disturbances and contribution to network restoration
- Safety, modularity, robustness, low losses, calibration and self-tuning

Parallel operation of inverters

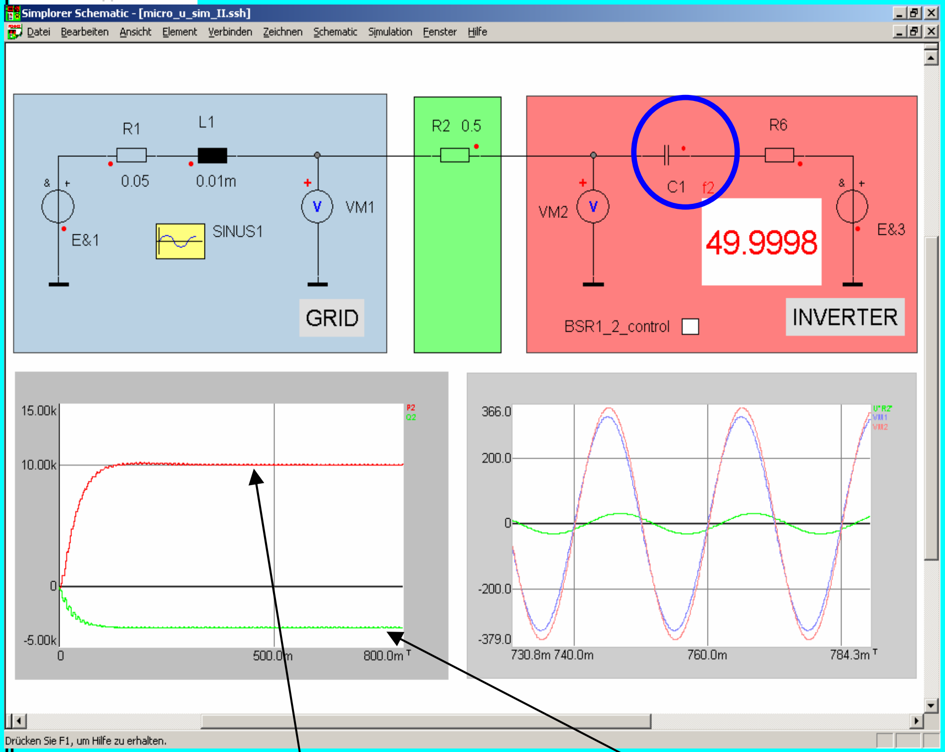


Frequency droop

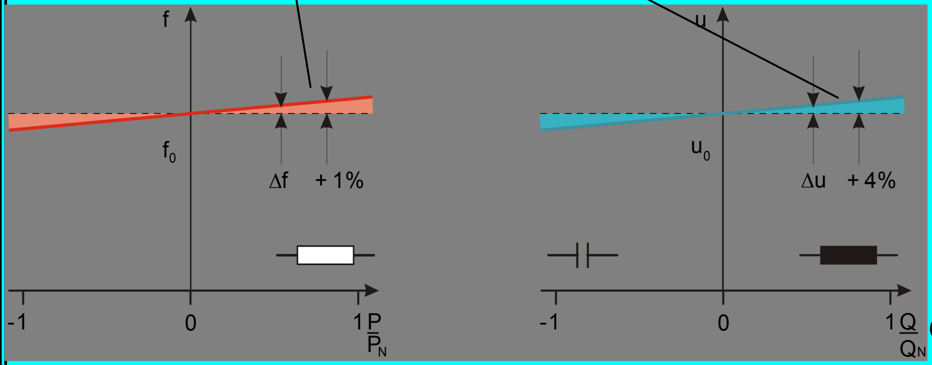
Voltage droop

- Droops for synchronising inverters with frequency and voltage!
- Frequency and voltage of the inverter is set according to active and and reactive power.

Voltage Regulation and Active Power control through droop



Drücken Sie F1, um Hilfe zu erhalten.



- Applied droop concept is based on inductive coupled voltage sources.

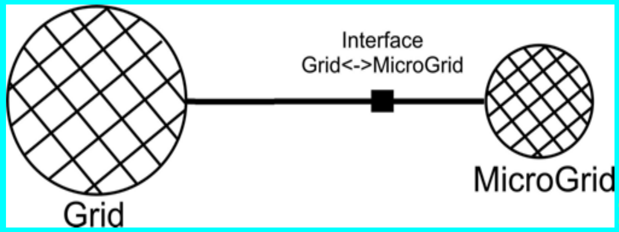
- In a LV-grid components are coupled resistive, thus voltage determines the active power distribution

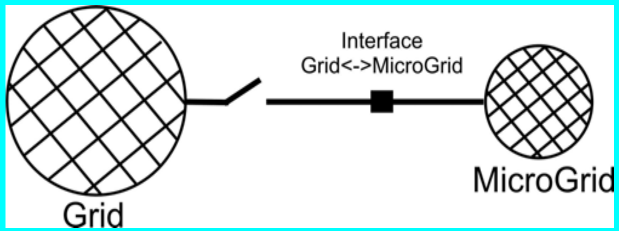
- There are two effects of droops
  - direct (inductive coupling)
  - indirect (resistive coupling)

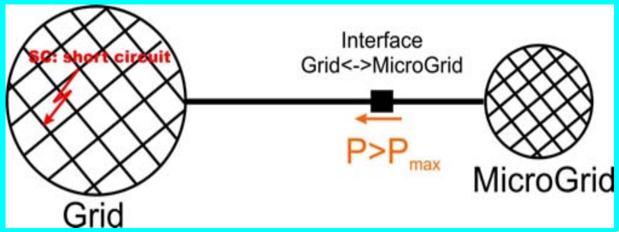
- The „indirect“ effect requires droops, which have the same sign for the frequency as well as the voltage droop and therefore the stable operation point is „in phase“.

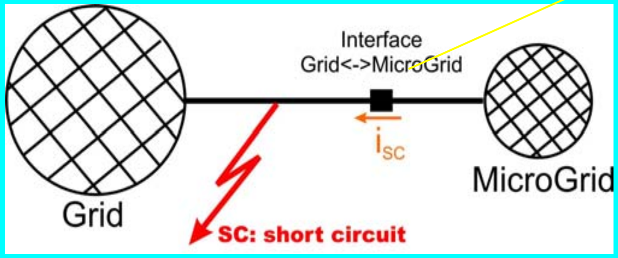
The compensation of lines was simulated and is recommendable. Overcompensation has to be avoided!

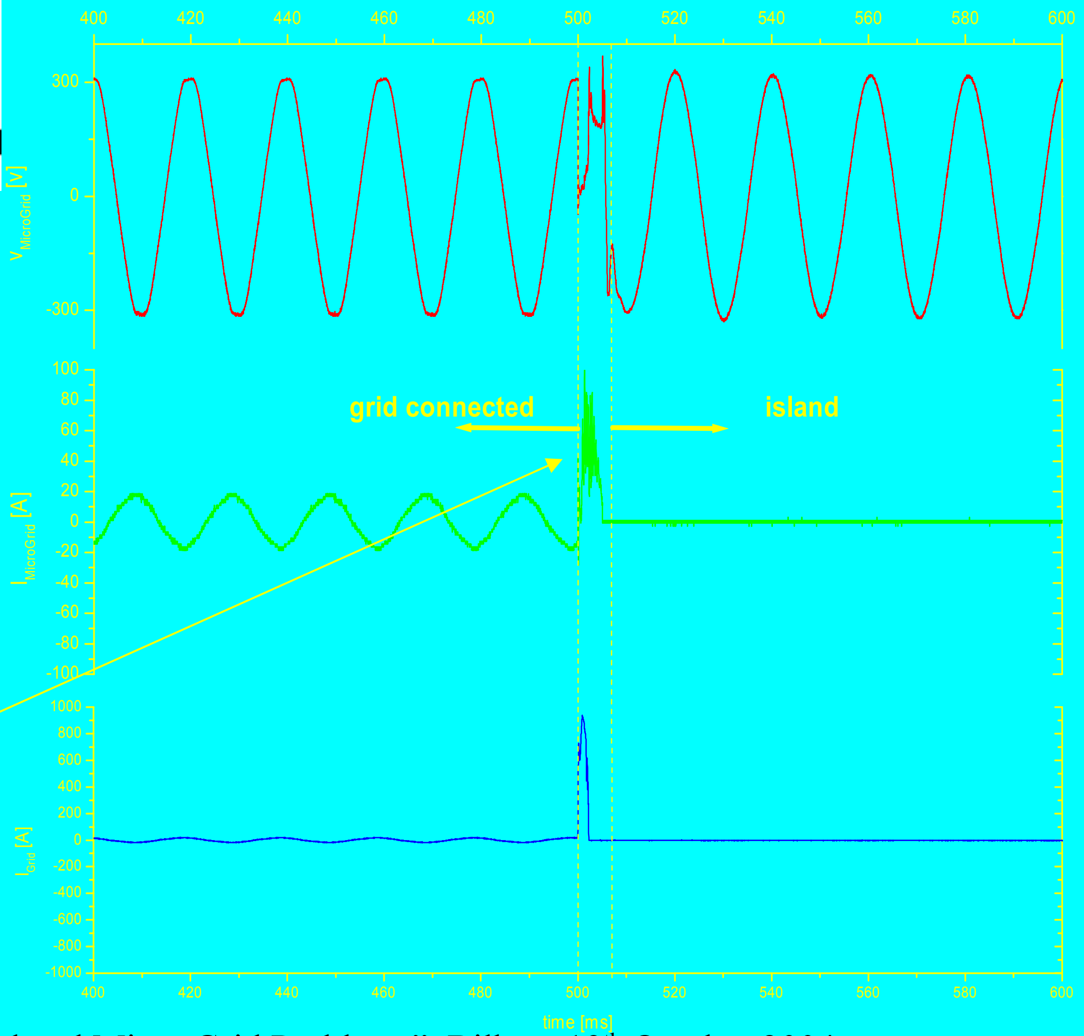
Development of Electronic Switch



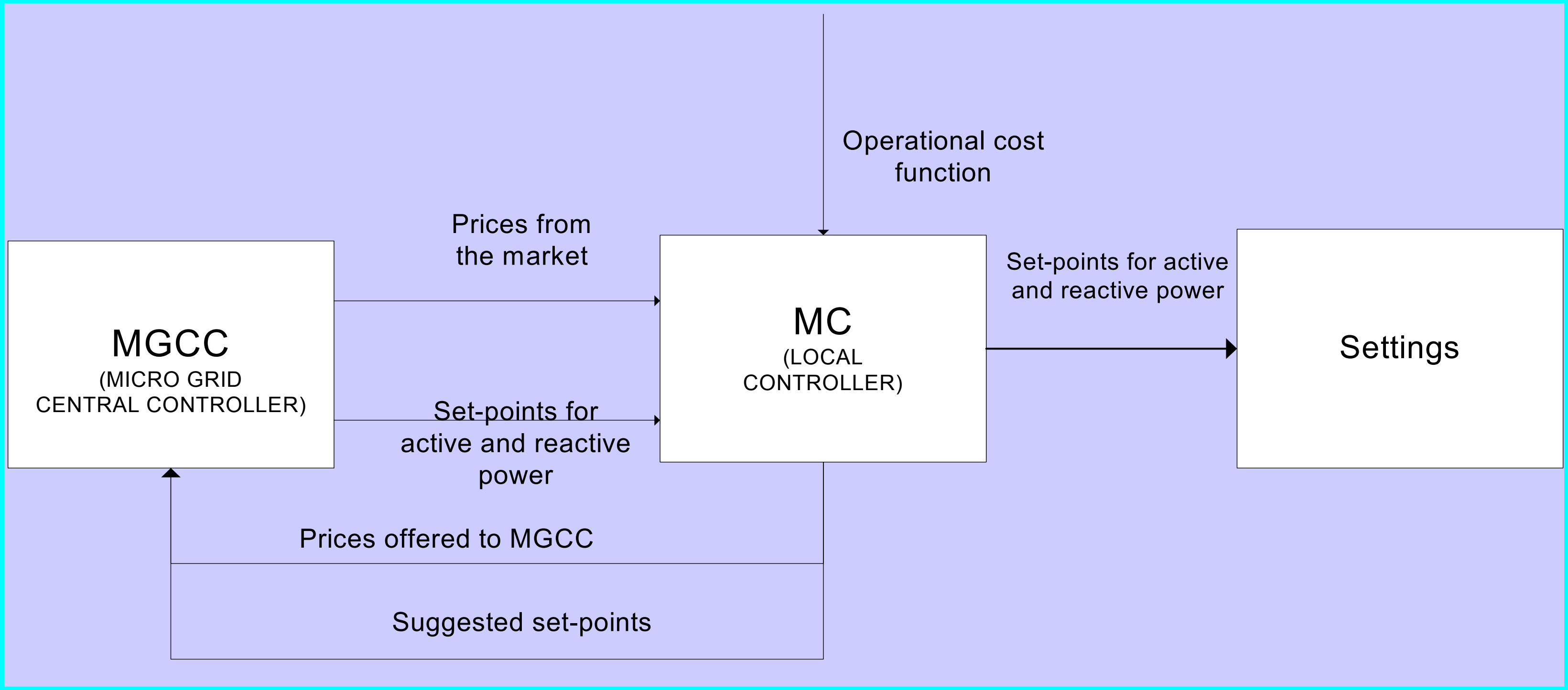








MicroGrid Central Controller



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

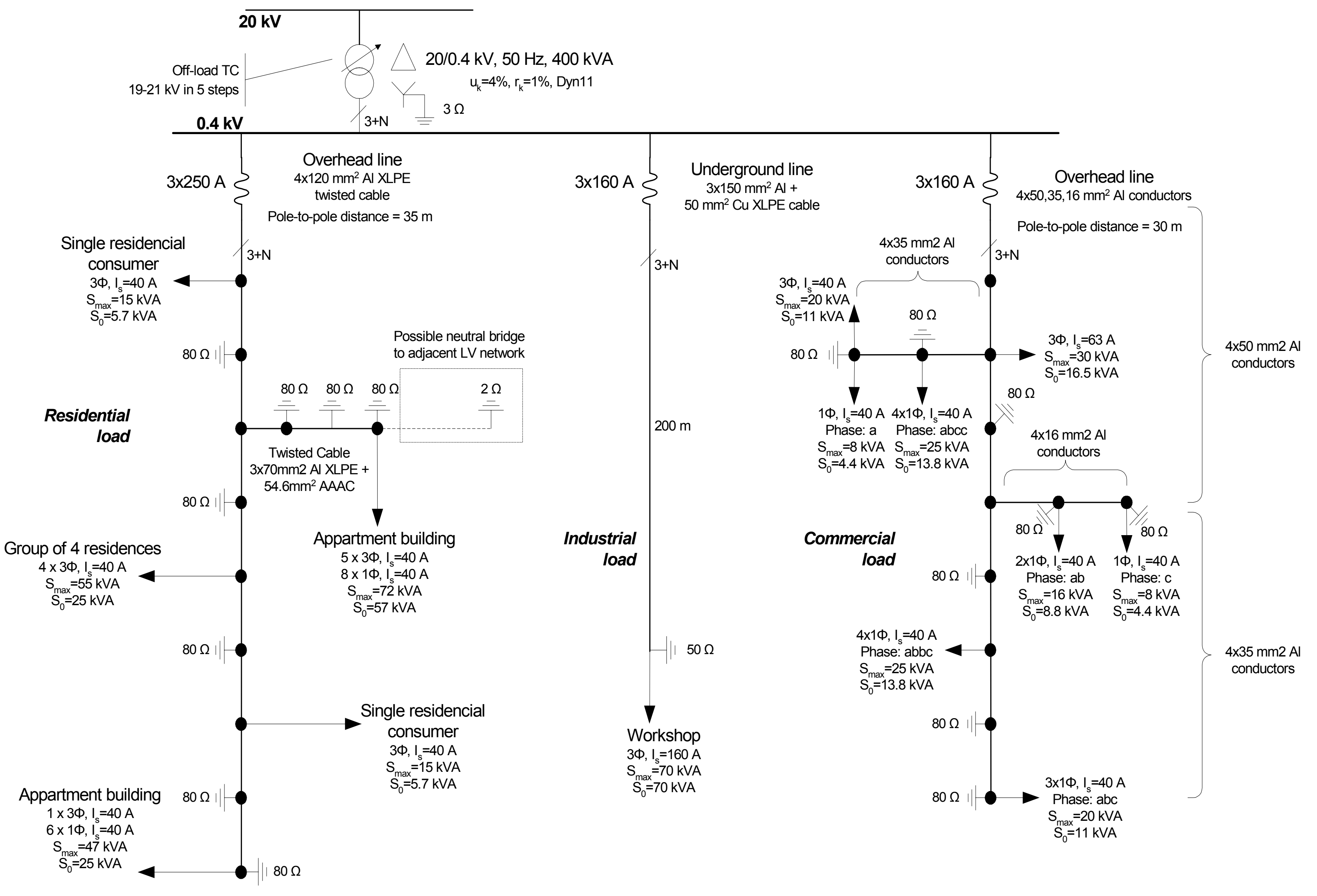
Policy 1- Microgrid serving its own needs

- “Good Citizen”
- MGCC tries to minimise the energy cost for the Microgrid knowing :
  - Prices of the open market for Active and Reactive power
  - Forecasted demand and renewable power production
  - Bids of the Microgrid producers.
  - Technical constraints

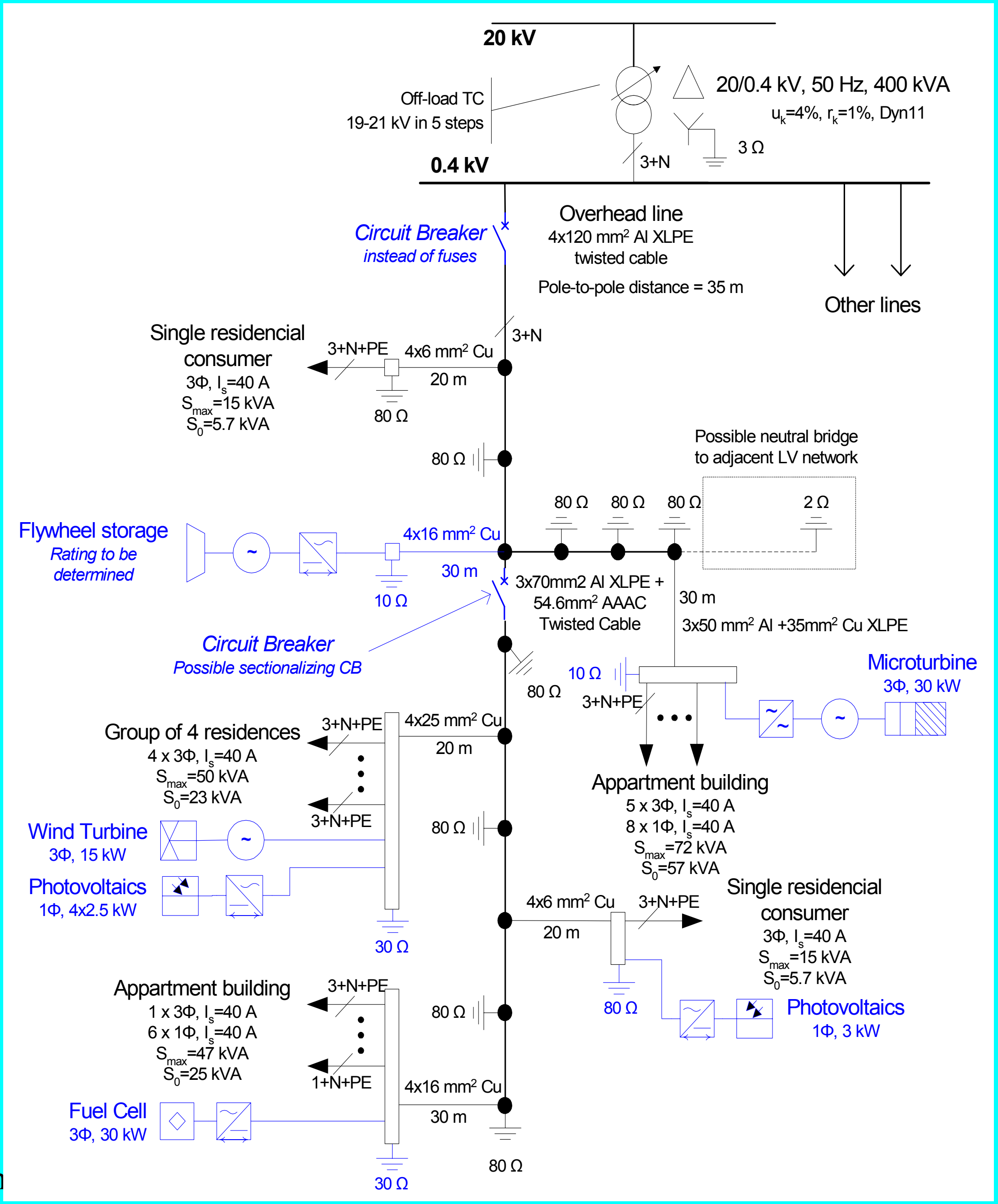
Policy 2-Buying and selling via an Aggregator

- "Ideal Citizen"
- The MGCC tries to maximise the value of the μ-sources knowing :
  - The market prices for buying and selling energy to the grid (Same prices for end-users of the Microgrid)
  - Demand and renewable production forecasting
  - The offers of the μ-sources
  - The technical constraints for the interconnection line and the μ-sources

LV network with multiple feeders



Study Case
LV Feeder
with DG
sources

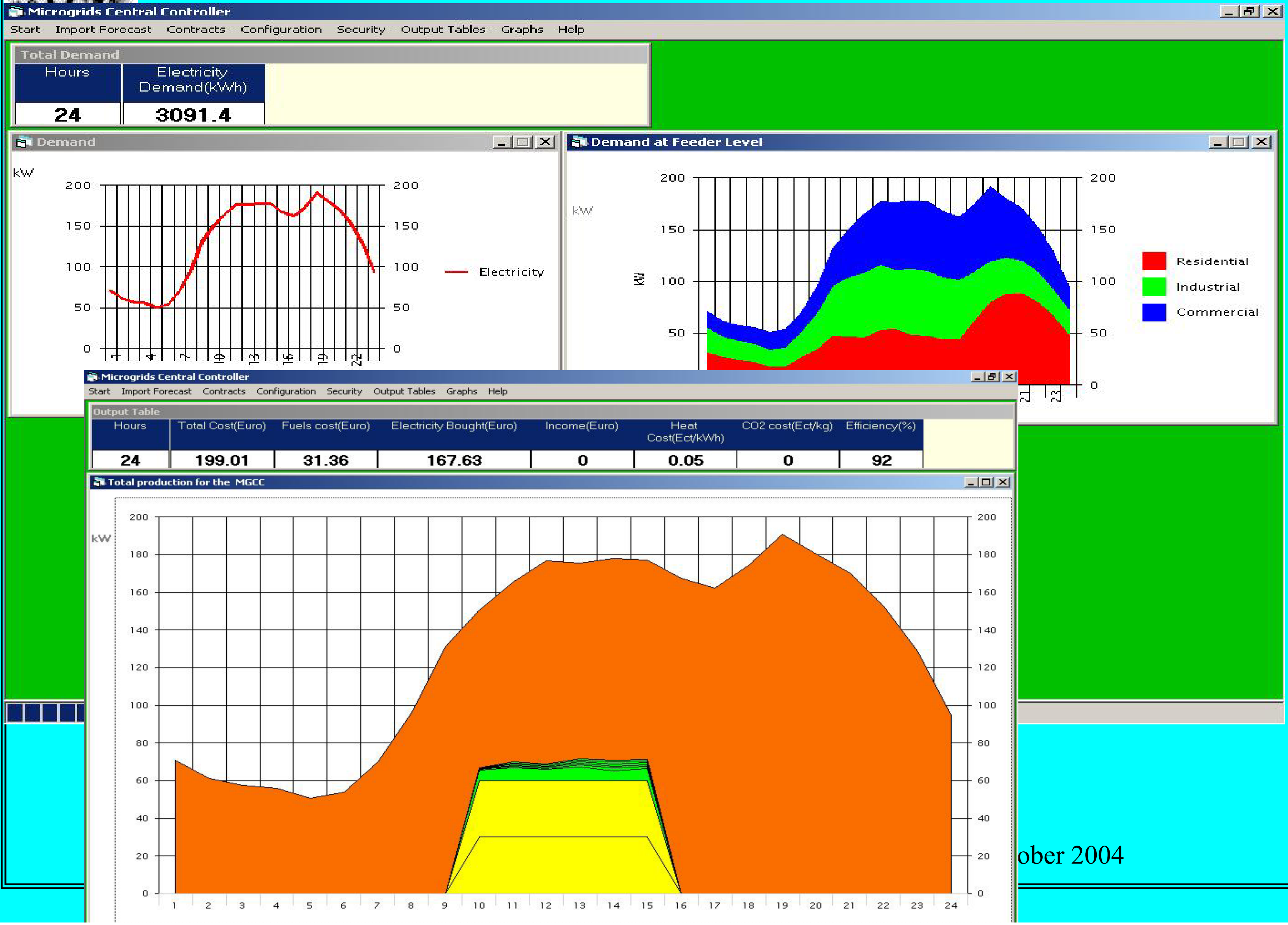


“Distributed Generation

Study Case of Microgrid Operation

- All three feeders taken into account
- Typical demand pattern and actual renewable power production time-series
- Amsterdam Power Exchange Prices.
- Bids from micro sources reflecting their production and installation cost
- Cost reduction of 6.6% for policies 1 and 2 without steady state security
- Steady state security increases cost by 6%.

Highlight: MGCC Simulation Tool



Total Demand

Hours	Electricity Demand(kWh)
24	3091.4

Output Table

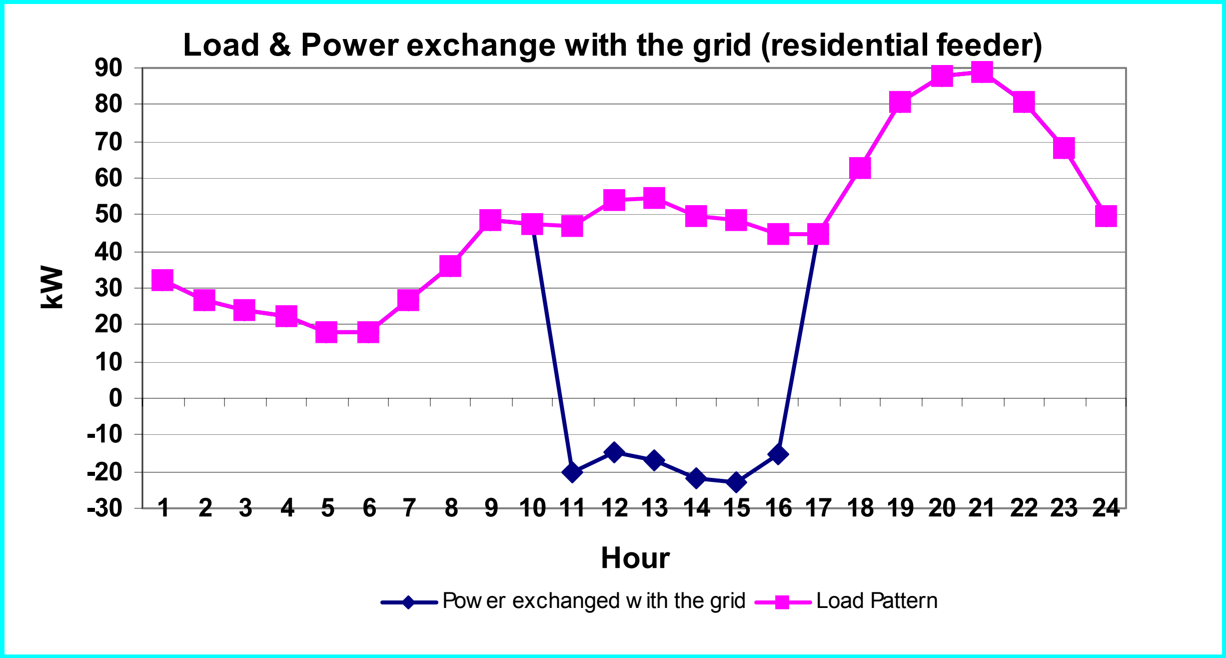
Hours	Total Cost(Euro)	Fuels cost(Euro)	Electricity Bought(Euro)	Income(Euro)	Heat Cost(Ect/kWh)	CO2 cost(Ect/kg)	Efficiency(%)
24	199.01	31.36	167.63	0	0.05	0	92

Residential Feeder with DGs

Policy1 Cost Reduction : 12.29 %

Policy 2 Cost reduction : 18.66%

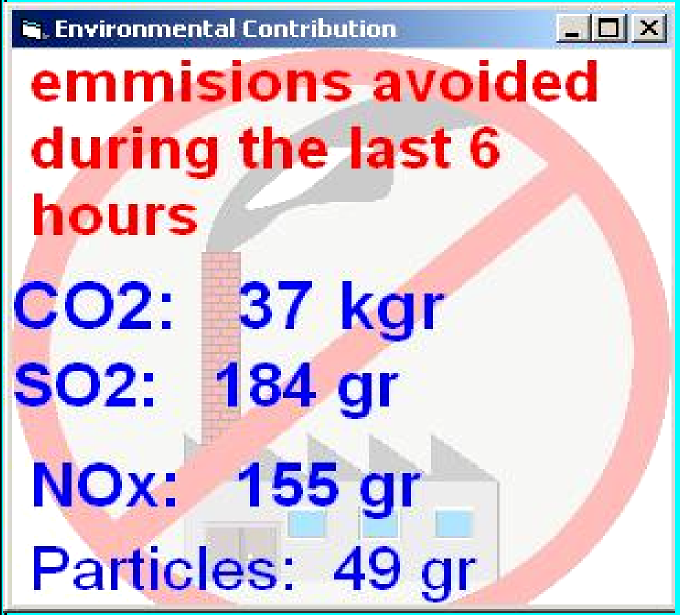
Greater cost reduction when selling to the Grid



Steady state security increases cost by 27% and 29% respectively.

Environmental Benefits

- Average values for emissions of the main grid
- Data about emissions of the μ-sources.



emmisions avoided during the last 6 hours

CO2: 37 kgr

SO2: 184 gr

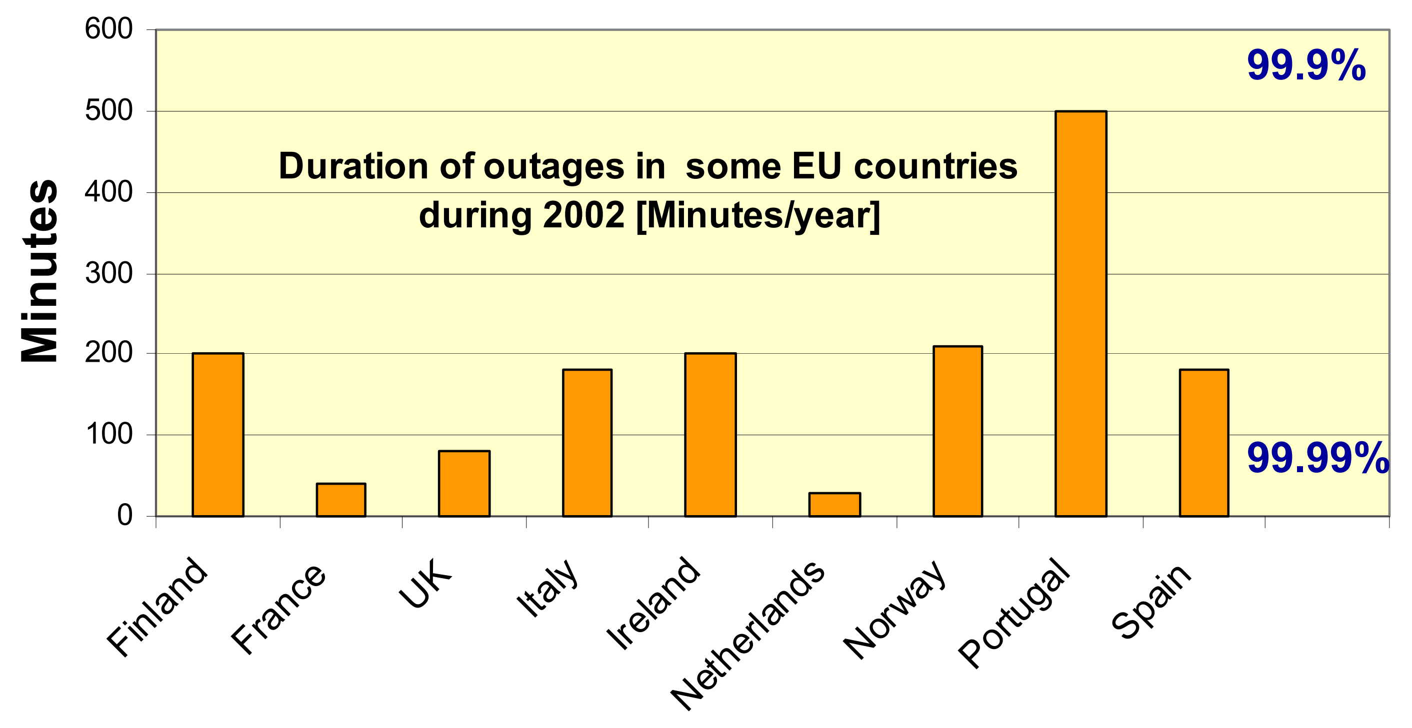
NOx: 155 gr

Particles: 49 gr

27% reduction in CO$_2$ emissions due to policy1

Maximum reduction in CO$_2$ emissions 548kgr/day- 22.11% higher cost

Annual duration of outage in some EU countries.

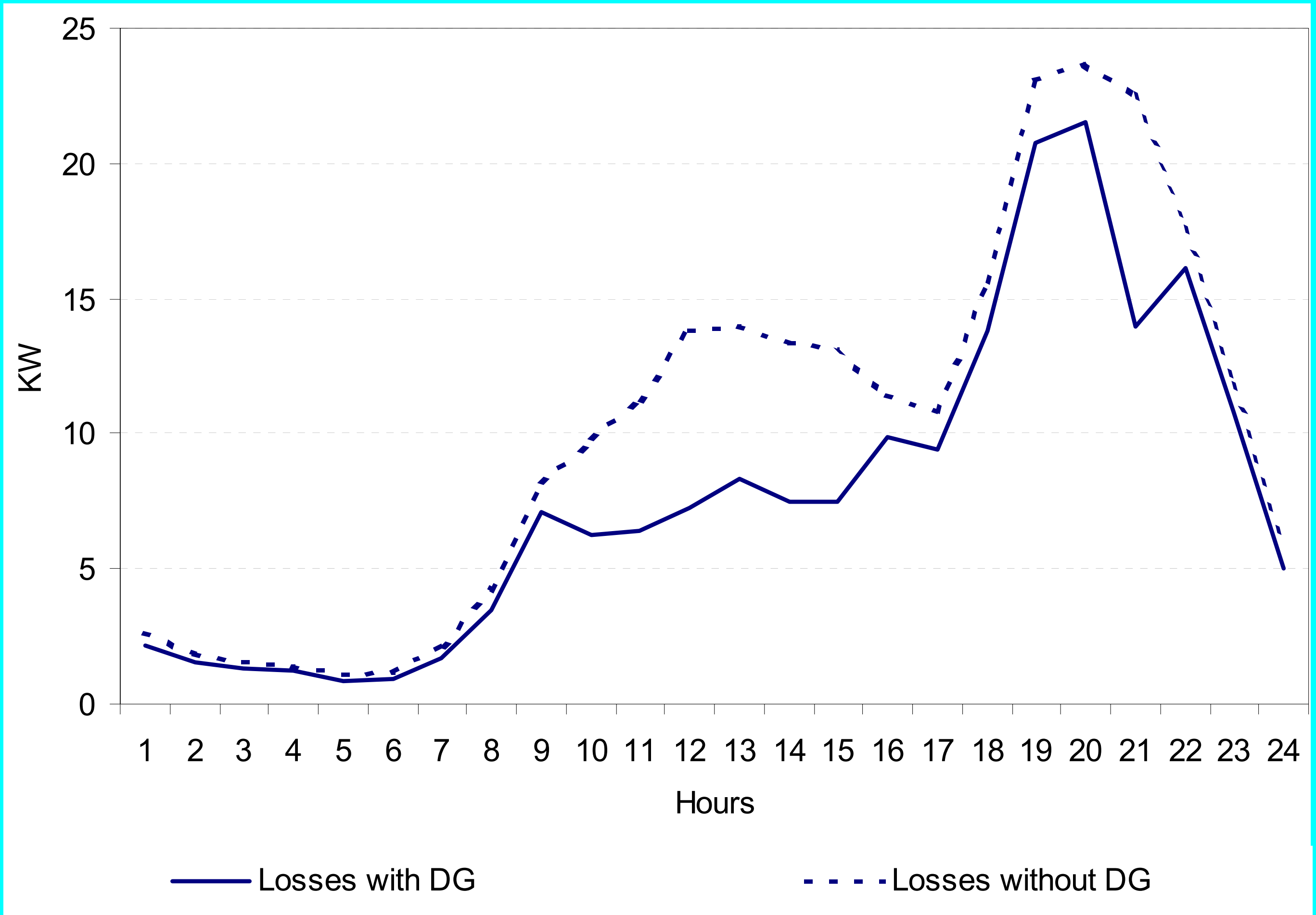


Source: Dolf De Loo. KEMA T&D Consulting

Highlight - Permissible expenditure to enable islanding

Customer Sector:		Residential	Commercial
Annual benefit	=	1.4 £/kW_{pk}	15 £/kW_{pk}
Net present value	=	15 £/kW_{pk}	160 £/kW_{pk}
Peak demand	=	2 kW	1000 kW
Perm. expenditure	=	£30	£160,000
MicroGrid (2,000kW)		£30,000	£320,000

Effects on Losses



Active power losses with and without DG

MICROGRIDS Highlight 3:
Reliability Assessment of LV Network

- System Maximum Load Demand: 188 kW
- Capacity of System Infeed: 210 kW (100%)
- Installed Capacity of Wind Generation: 15 kW
- Installed Capacity of PVs: 4*2,5+1*3 = 13 kW
- Installed Capacity of Fuel Cells: 30 kW
- Installed Capacity of Microturbines: 30 kW

Reliability Assessment

	FLOL (ev/yr)	LOLE (hrs/yr)	LOEE (kWh/yr)
Infeed Capacity 100% (no microsources)	2,130	23,93	2279,03
Infeed Capacity 80% (no microsources)	58,14	124,91	3101,52
Infeed Capacity 80% (with Wind + PV)	14,02	41,67	2039,41
Infeed Capacity 80% (all microsources)	2,28	15,70	716,36

Reliability Assessment – continued

	FLOL (ev/yr)	LOLE (hrs/yr)	LOEE (kWh/yr)
Infeed Capacity 90% (no microsources)	8,52	31,08	2313,77
Infeed Capacity 90%, system load 207 kW (+10%) (no microsources)	44,10	92,75	3073,84
Infeed Capacity 90%, load 207 kW (with Wind + PV)	11,35	36,69	2232,54
Infeed Capacity 90%, load 207 kW (all microsources)	2,305	16,55	911,68

Modelling and simulation of MicroGrids

- modelling of generator technologies (micro generators, biomass fuelled generation, fuel cells, PV, wind turbines), storage, and interfaces
- load modelling and demand side management
- unbalanced deterministic and probabilistic load flow and fault calculators
- unbalanced transient stability models
- stability and electrical protection
- simulation of steady state and dynamic operation
- simulation of interactions between Microgrids

Main Characteristics of LV Distribution Networks

- Radial or meshed network development
- R comparable or even greater than X (R/X ~ 5)
- Unbalanced excitation (loading or generation)
- Unbalanced network conditions
    - Single phase network sections
    - Mutual coupling between network components
- Various earthing arrangements
    - TN (TN-S, TN-C)
    - TT
    - IT

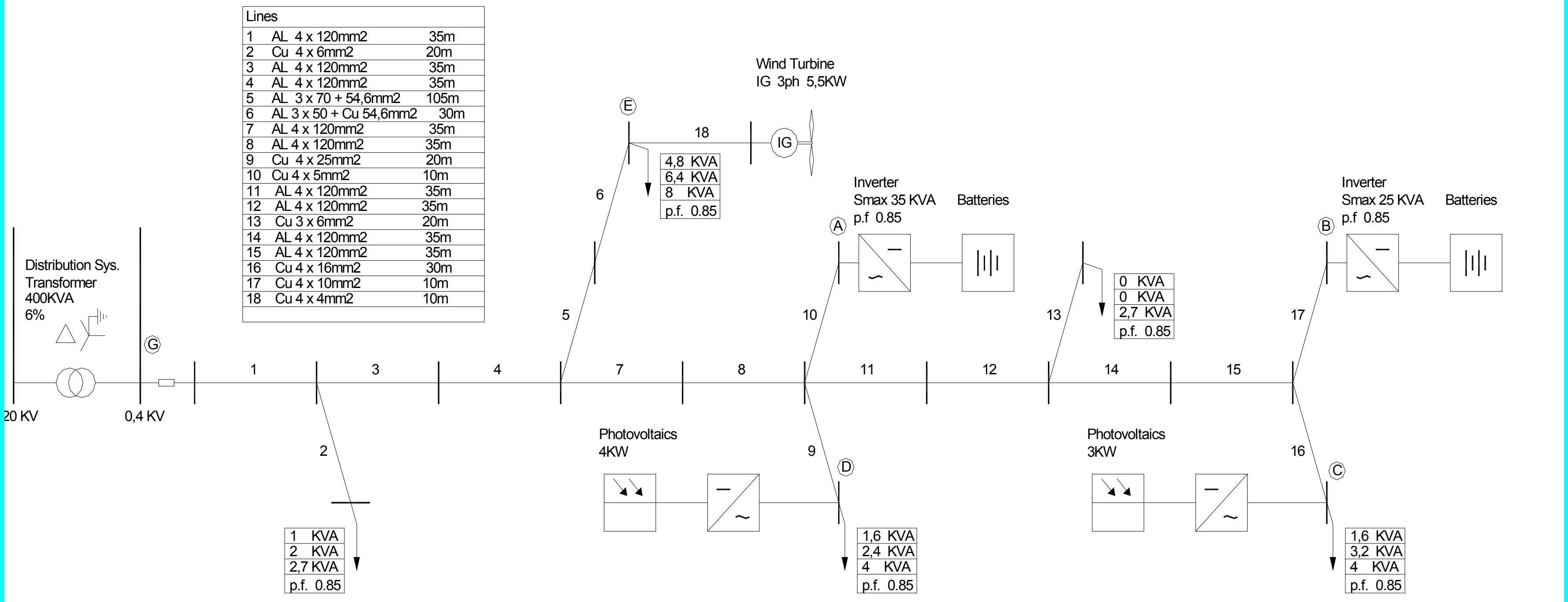
Main Characteristics of Simulation Tool

- **Phasor approach** adopted for network and sources to increase simulation efficiency.
- Natural **phase quantities** (a-b-c) are used.
- Microsources represented as **EMFs behind impedance**, neglecting “stator transients”.
- Lines with **any X/R ratio** can be handled.
- **Radial and non-radial** network topologies. All basic **neutral earthing schemes** can be represented (TN, TT, IT).

Main Characteristics of Simulation Tool/2

- **Unbalanced conditions** (network, sources, loads) can be modelled and simulated.
- Dynamic simulation of **grid-connected and autonomous** mode of operation.
- Microsources integrated in the code with their respective **electronic interfaces**.
- Simulation tool based on **Matlab and Simulink**. **Matlab** for the core network solver, initialization and post-processing, **Simulink** for prime movers, controls and numerical integration.

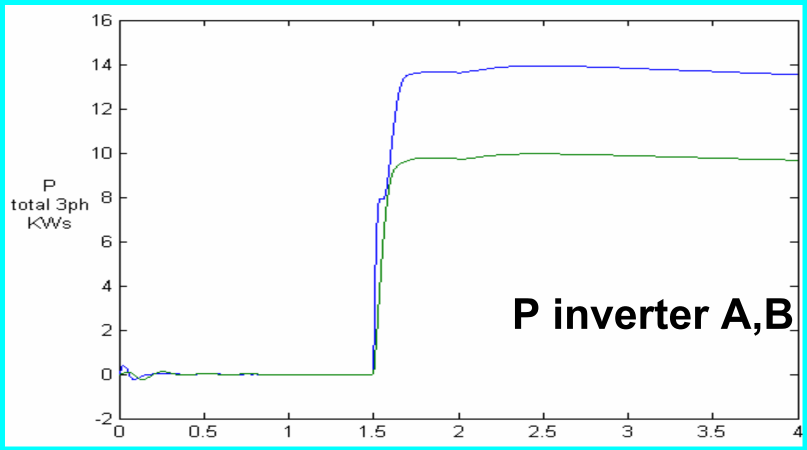
Simulated Microgrid

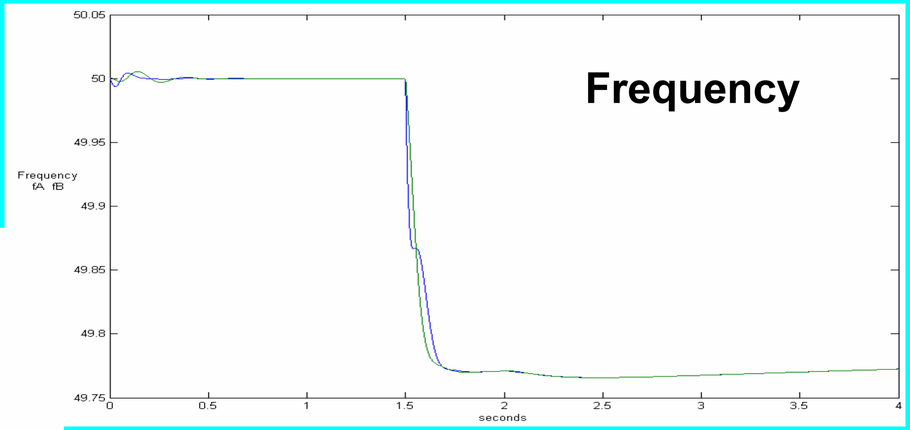


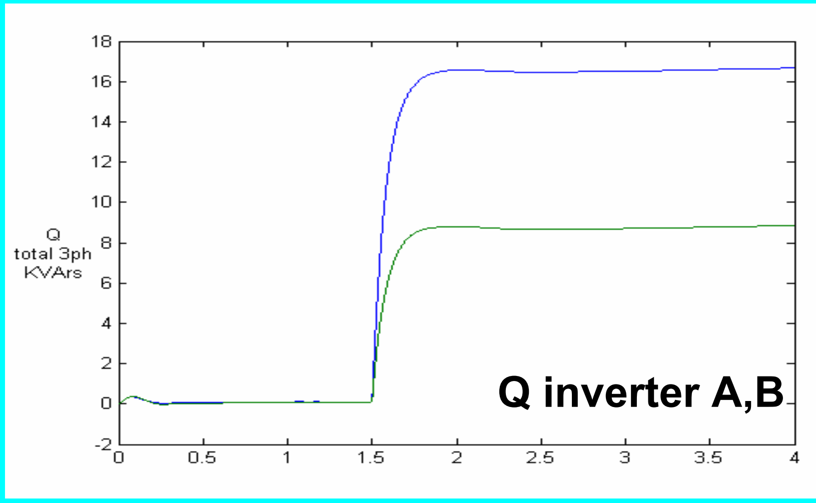
Lines		
1	AL 4 x 120mm2	35m
2	Cu 4 x 6mm2	20m
3	AL 4 x 120mm2	35m
4	AL 4 x 120mm2	35m
5	AL 3 x 70 + 54,6mm2	105m
6	AL 3 x 50 + Cu 54,6mm2	30m
7	AL 4 x 120mm2	35m
8	AL 4 x 120mm2	35m
9	Cu 4 x 25mm2	20m
10	Cu 4 x 5mm2	10m
11	AL 4 x 120mm2	35m
12	AL 4 x 120mm2	35m
13	Cu 3 x 6mm2	20m
14	AL 4 x 120mm2	35m
15	AL 4 x 120mm2	35m
16	Cu 4 x 16mm2	30m
17	Cu 4 x 10mm2	10m
18	Cu 4 x 4mm2	10m

Study Case E

Two battery invs + two PVs + one WT - Isolation + wind fluctuations







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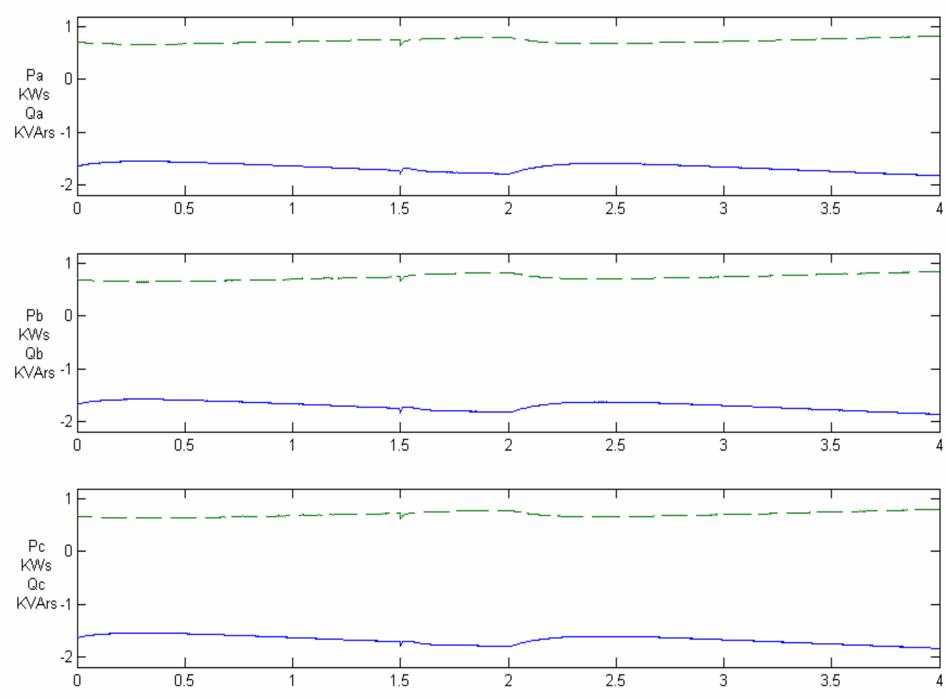
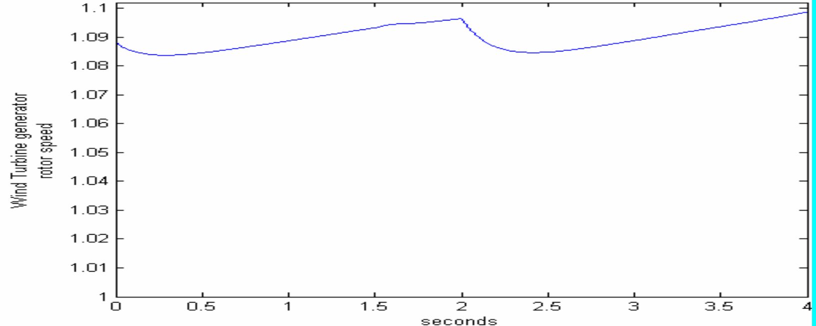


P,Q per phase WT

Rotor speed WT



Study Case E

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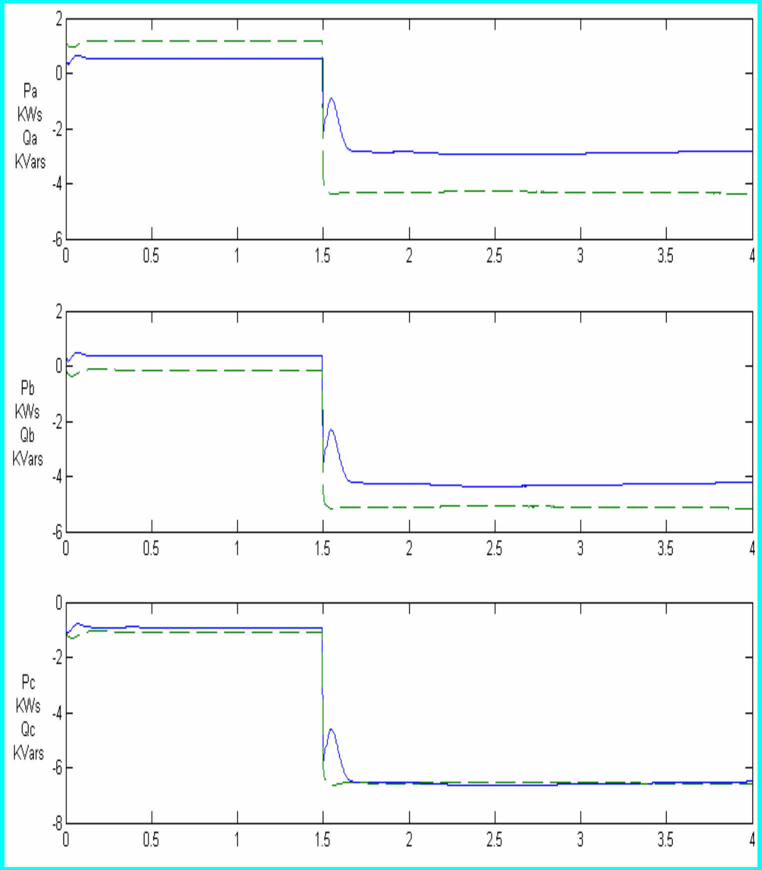
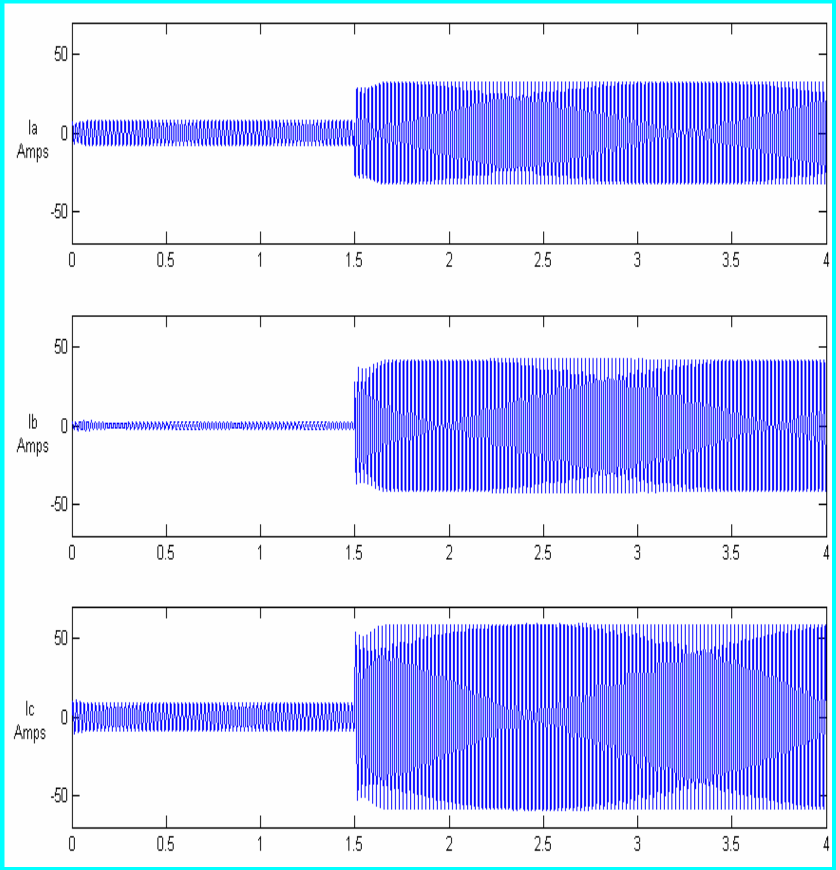


P,Q per phase inverter A



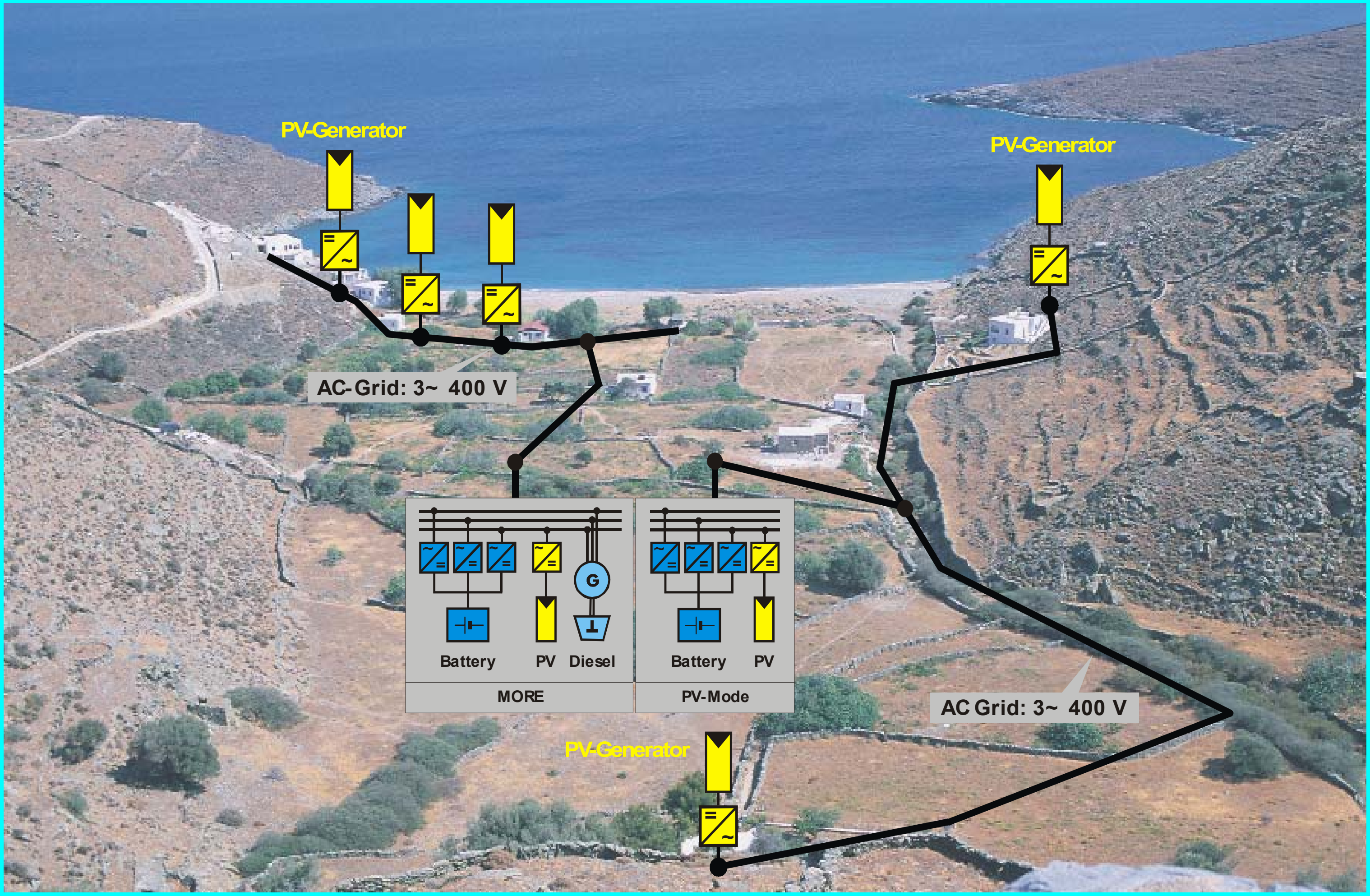
I per phase inverter A

Further Needs Identified

- More sophisticated control techniques for local Distributed Resource and load controllers to implement
- Study of integration of several Microgrids into operation and development of the power system. Interaction with DMS.
- Need for standardization and benchmarking.
- **Field trials to test control strategies on actual Microgrids**
- **Need for quantification of Microgrids effects on Power sysetm operation and planning**
- Need for cooperation and learning from alternative, complementary approaches, under development in US, Canada and Japan

The Kythnos Microgrid - CRES

Pilot plant on Kythnos – Testing Control



- Supply of 12 buildings (EC projects MORE and PV-Mode)

The Kythnos Microgrid

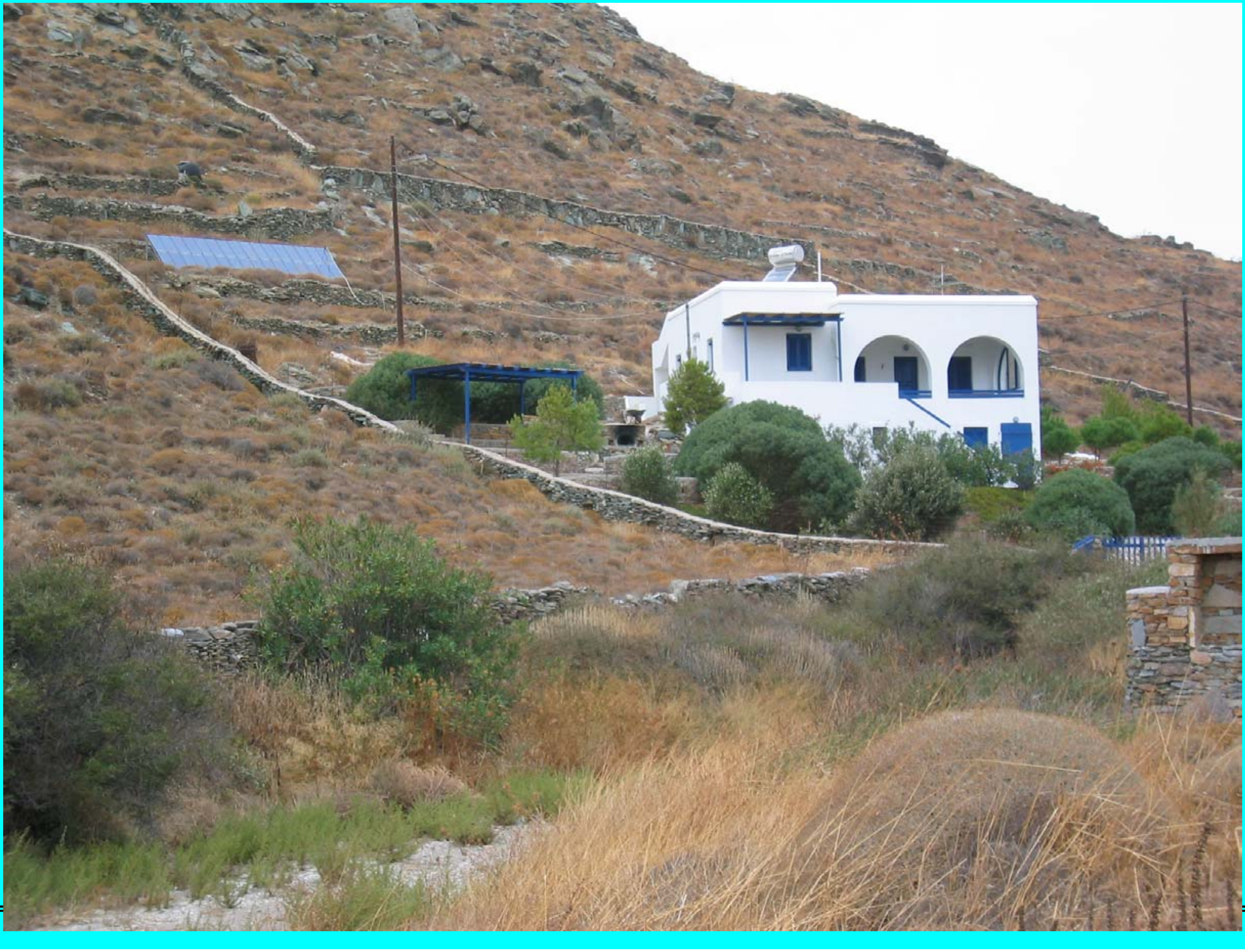
The Kythnos Microgrid

The Kythnos Microgrid

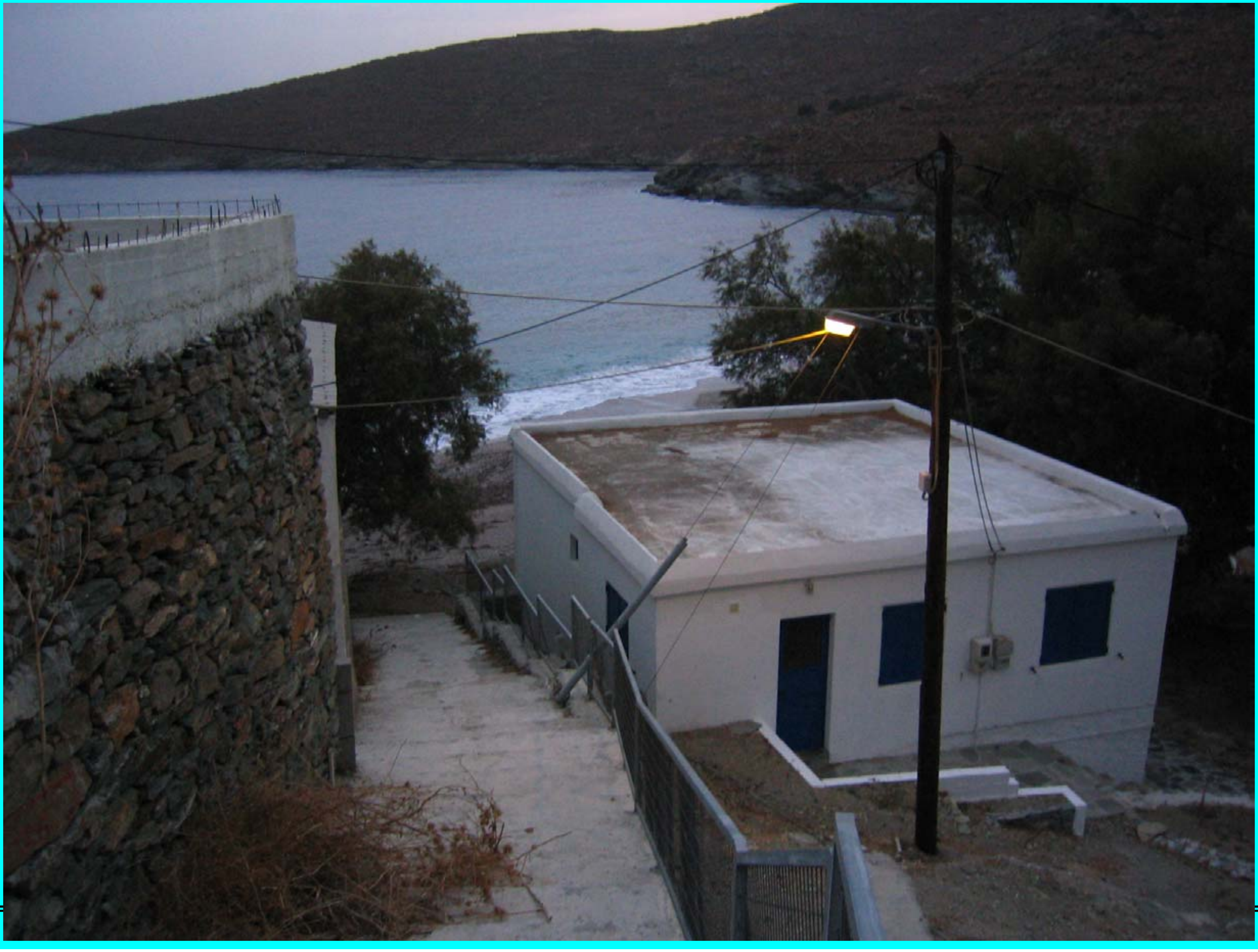
The Kythnos Microgrid

The Kythnos Microgrid

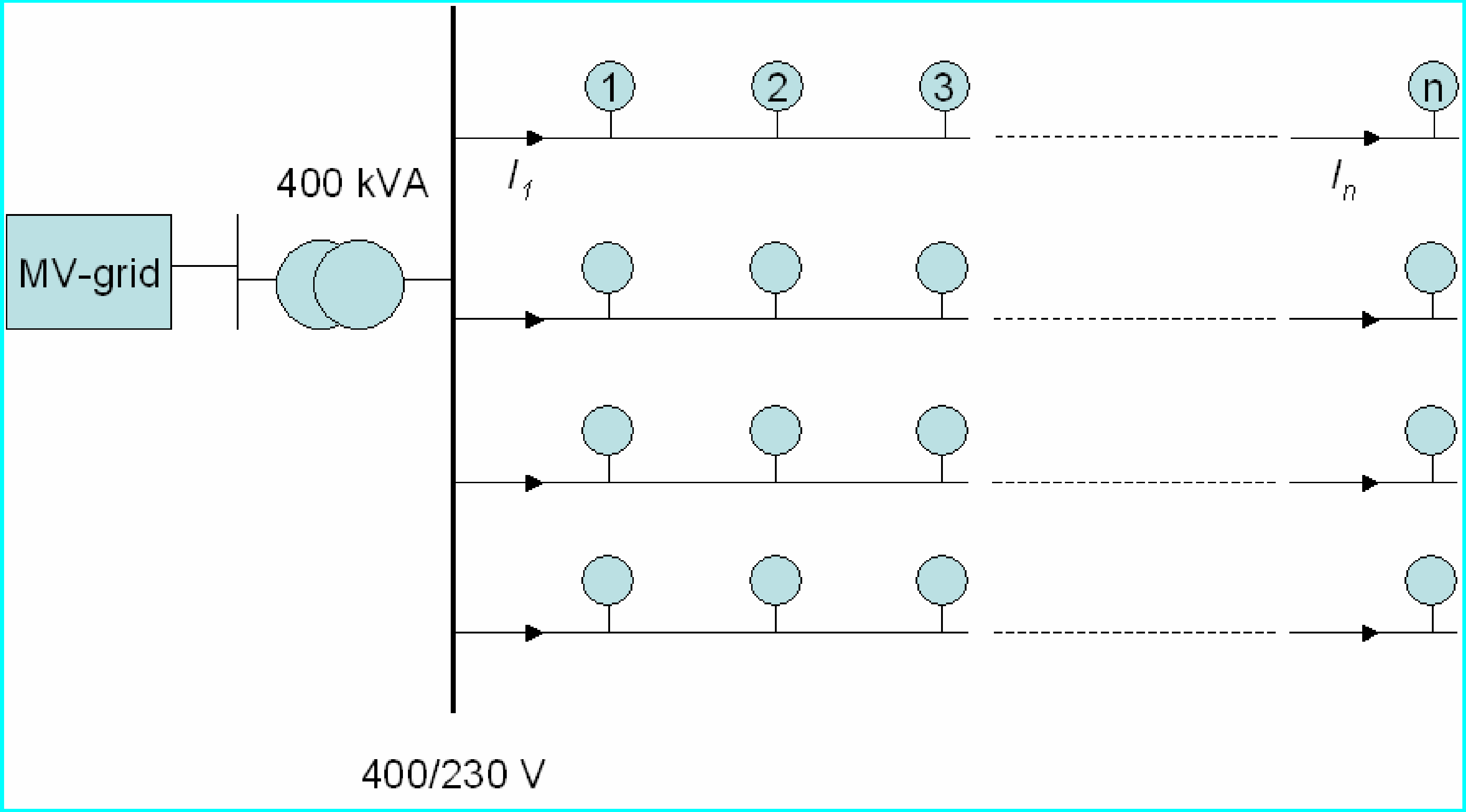
The Kythnos Microgrid



The Kythnos Microgrid

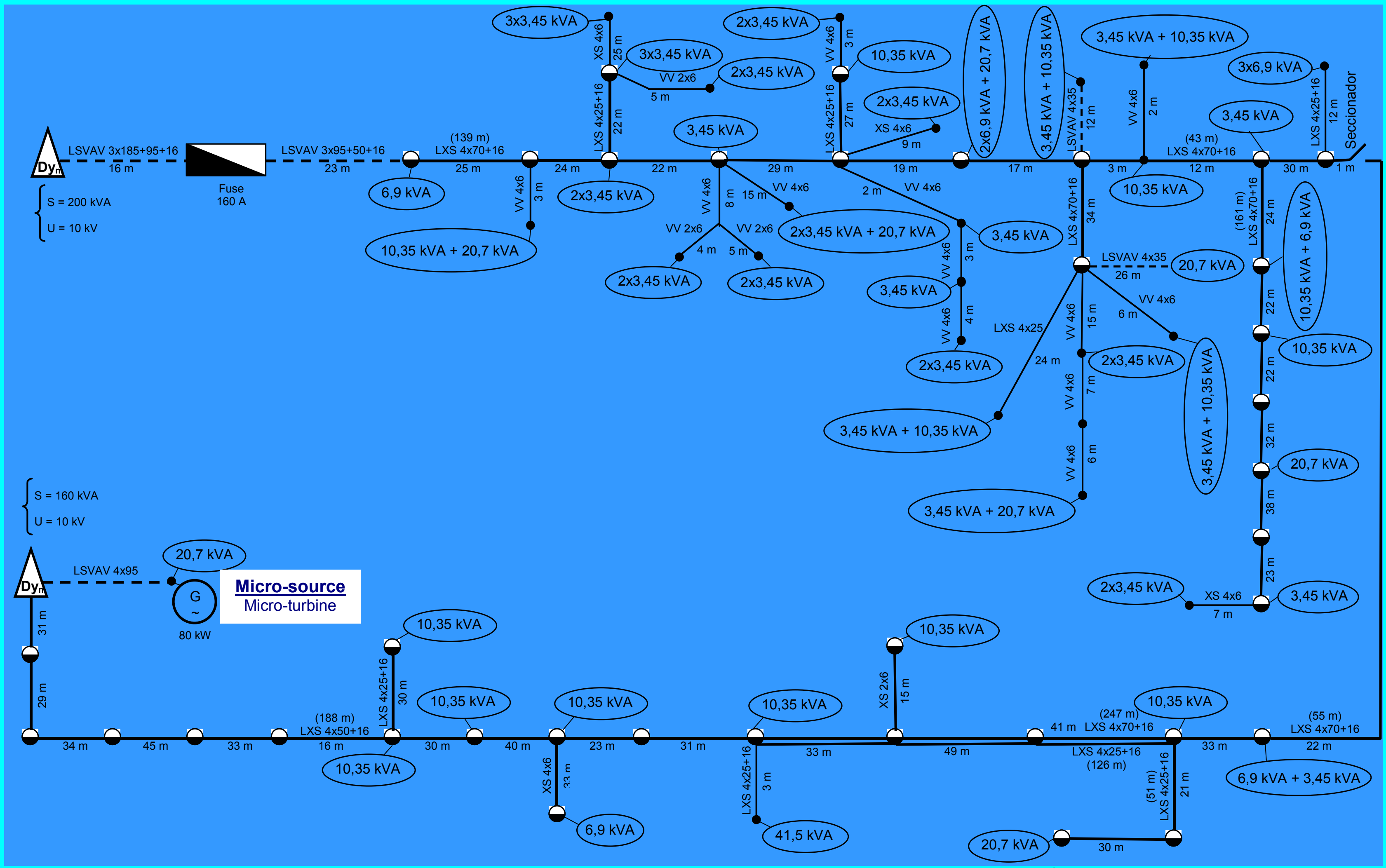


Holiday-Parc Bronsbergen, Zutphen, The Netherlands - CONTINUON



More then 200 cottages. A great number equipped with PV-generators (315 kW), coupled to the grid by means of inverters

EDP Study Case



“Distributed Generation, Grid and Micro Grid Problems”, Bilbao, 19th October 2004

Microturbine – Testing Transfer

Conclusions

- Microgrids: A new paradigm for future power systems
- Distinct advantages regarding efficiency, reliability, network support, environment, economics
- Challenging technical and regulatory issues
- Needs for benefits quantification

http://microgrids.power.ece.ntua.gr