# DER and Microgrids: Research Topics within EU Framework Programs

Nikos Hatziargyriou
nh@power.ece.ntua.gr
National Technical University of Athens, Greece

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# Sustainable Energy Systems
# DRIVING FORCES



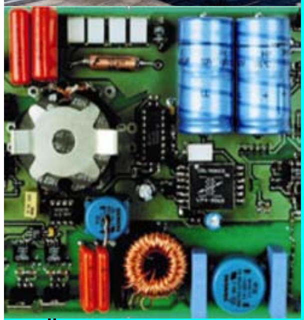
- **Energy Policy:**
  - ❑ Market liberalisation and competitiveness
  - ❑ External dependency and security of supply
  - ❑ Energy efficiency and technological development

- **Environment Policy:**
  - ❑ Kyoto and Göteborg commitments for a sustainable development

- **R&D&T and innovation Policy:**
  - ❑ Lisbon Strategy and the European Research Area

# Sustainable Energy Systems
# Legislative instruments





- **Electricity internal market, 97/98 & 2003**
- **Electricity from RES, September 2001**
- **Energy efficiency in buildings, December 2002**
- **Bio-fuels for transport, May 2003**
- **Emission right trade, Oct 2003**
- **Co-generation, February 2004**

# Drivers for Energy Research in EU

## Security of supply

☑ 50% external dependence

☑ reliance on fossil fuels ☑ need diversification of sources **(RES)**

## Climate change

☑ "one of the greatest challenges of our generation"

☑ energy ⇔ $CO_2$ ☑ need clean energy **(RES)**

## Competitiveness of the European industry

☑ competitiveness (Lisbon objectives) ☑ sustainable development ☑ energy is a growth market **(RES)**

# Key considerations for "Electricity with large DER"

- **Security of supply** – efficient mix of centralised with decentralised operation allows the use of domestic energy resources, whilst maintaining a high level of reliability and quality of supply.

- **Climate change** – higher efficiency in energy transport and use of RES and cleaner Distributed Generation, incl. CHP, results in a real contribution to reduce emissions.

- **Competitiveness of European Industry** – enhancement and renewal of the electricity infrastructure networks represents a huge investment/markets, both in the EU and worldwide.

# RTD Electricity in FP5-6:
## large scale"integration" of RES+DG

- ❑ Validation of advanced grid architectures
- ❑ Large Scale Virtual Power Plants
- ❑ Network of Excellence for DER laboratories
- ❑ Co-ordination Action for European DER
- ❑ Power electronics
- ❑ High Temperature Superconductivity
- ❑Future European Electricity Transmission Networks

# FP5 (1998-2002) funded research

## large-scale "integration" of RES+DG

| Research Area: INTEGRATION DER | Number of projects | Total Budget [M€] | EC funding [M€] |
|---|---|---|---|
| Distributed Generation | 8 | 34.29 | 18.99 |
| Transmission | 4 | 9.74 | 5.72 |
| Storage | 20 | 45.31 | 20.73 |
| HT Superconductors | 6 | 11.27 | 6.16 |
| 'Other' | 17 | 29.12 | 15.21 |
| TOTAL | 55 | 129.73 | 66.81 |

# FP6 (2002-2006) funded research

## large-scale Integration of RES+DG

| Research Area: INTEGRATION DER | Number of projects | Total Budget [M€] | EC funding [M€] |
|---|---|---|---|
| Advanced Architectures and Operation concepts | 7 | 65.50 | 33.35 |
| Transmission | 2 | 7.07 | 4.95 |
| Storage | 1 | 5.87 | 5.00 |
| HT Superconductor Devices for networks | 2 | 7.82 | 3.35 |
| Advanced Power Electronics | 2 | 5.25 | 3.41 |
| TOTAL | 14 | 91.51 | 50.06 |

# Main lessons learned so far

**FP5&6 funded research large-scale Integration of RES+DG**

- **Non-technical issues** are critical today
- **Main technical issues** are reliability, safety and quality of power
- **Real-time information** is critical
- Few **possible concepts for smart power grids**, but final solutions still unclear
- Impact on **transmission networks** should be further considered.
- **Emerging results** are being exploited
- **International dimension recognized under ERA**
- **Co-operation and co-ordination** of stakeholders in the context of a Technology Platform

# *Cooperation* – Collaborative research

DRAFT

## *9 Thematic Priorities*

1. **Health**
2. **Food, agriculture and Biotechnology**
3. **Information and Communication Technologies**
4. **Nanosciences, Nanotechnologies, Materials and new Production Technologies**
5. **Energy**
6. **Environment and climate change**
7. **Transport**
8. **Socio-Economic Sciences and the Humanities**
9. **Space and Security research**

# 5. Energy

DRAFT

- Hydrogen and fuel cells
- Renewable electricity generation
- Renewable fuel production
- Near zero emission power generation
- Smart energy networks
- Energy savings and energy efficiency
- Knowledge for Energy policy making

# Preparation of FP7

**Smart Power Networks:** **Research and demonstration needs for "Integration" of DER/RES.**

- **Aimed at removing all obstacles to larger development of DER/RES**
- **Ensure functioning of the EU electricity market, addressing the issues of security, reliability and quality of supply**
- **Provide appropriate knowledge for technical solutions and regulatory approaches.**

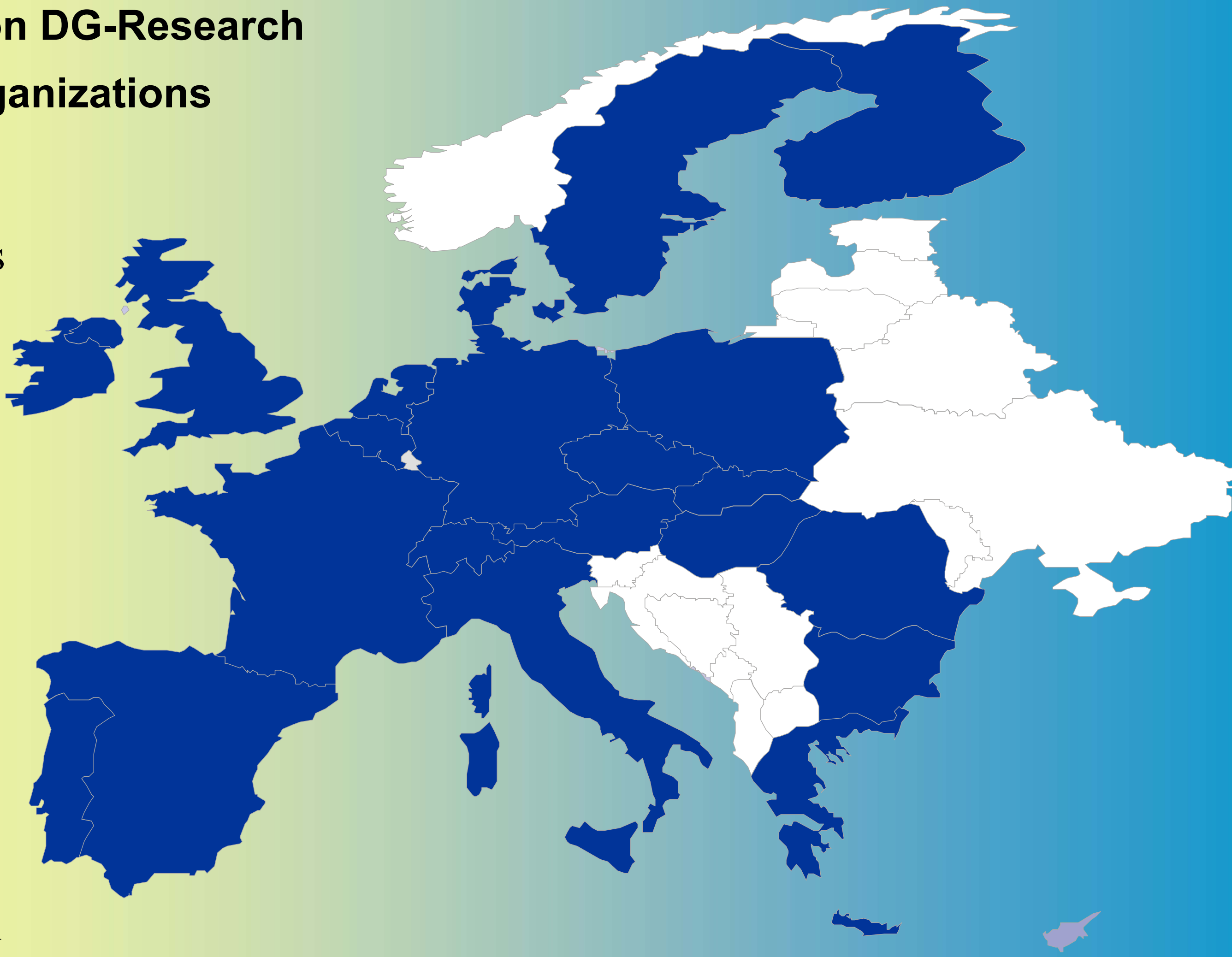
# 5th (EC) RTD Framework Programme (1998-2002)

## “Integration of Renewable Energies + Distributed Generation”

**European Commission DG-Research**

**Over 100 different organizations**

**34 Mio. Euro**

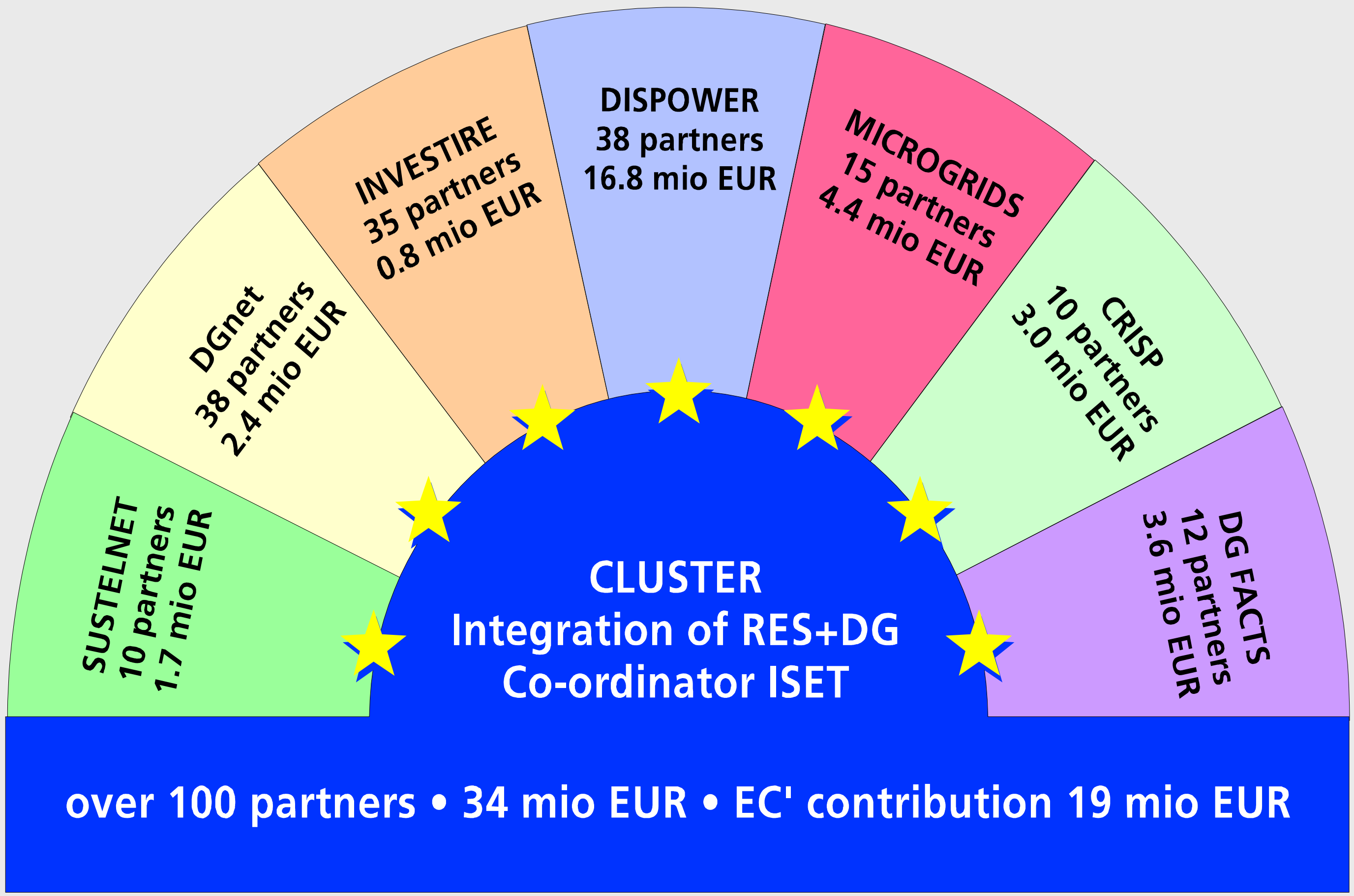


- Concentrating efforts and maximising critical mass
- Creating real European added value in support of European policy making towards mobilising research
- Identifying highest priority research topics in this field
- Improving links with policies and schemes

Source: M. Sánchez -Jimenez

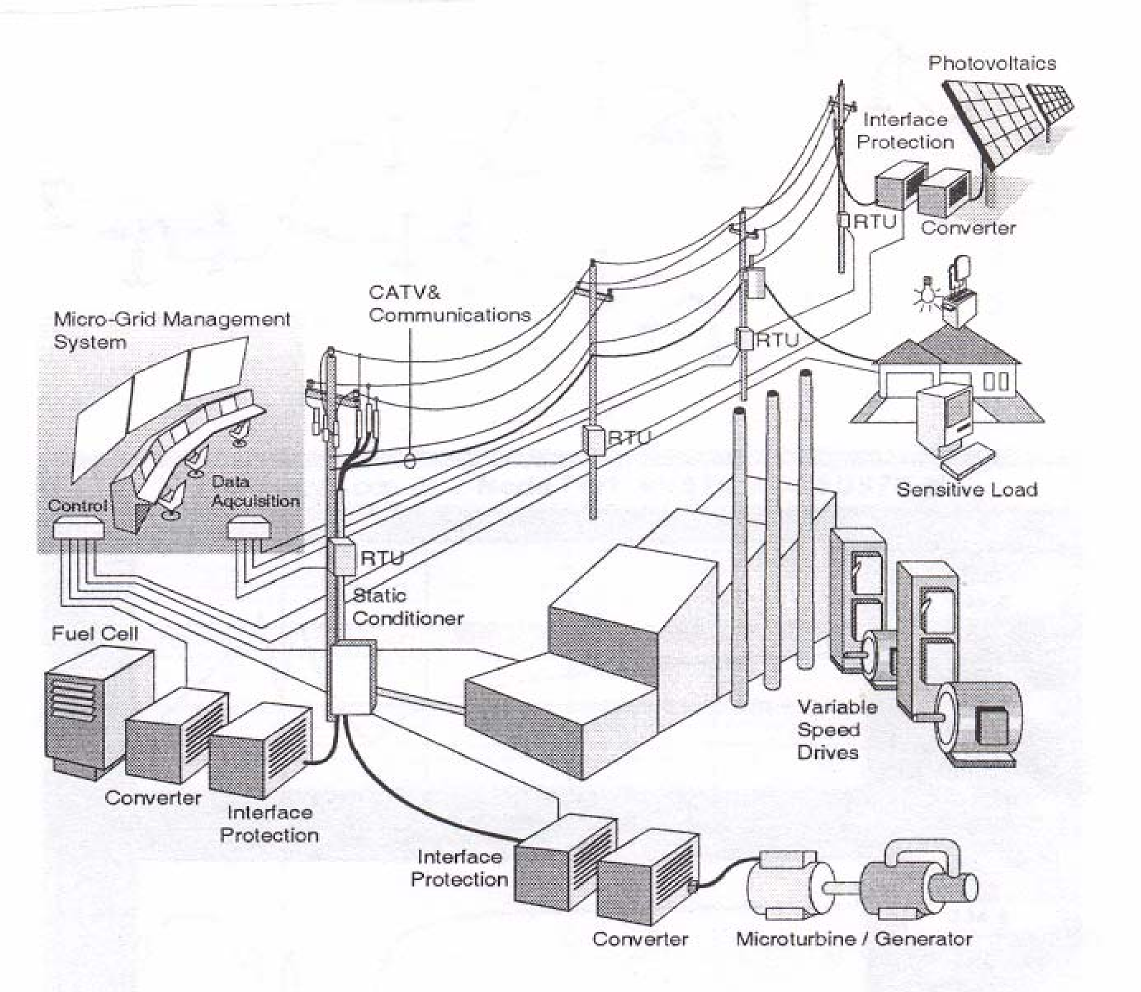
Cluster

# "Integration of Renewable Energies + Distributed Generation"



# What are MICROGRIDS?

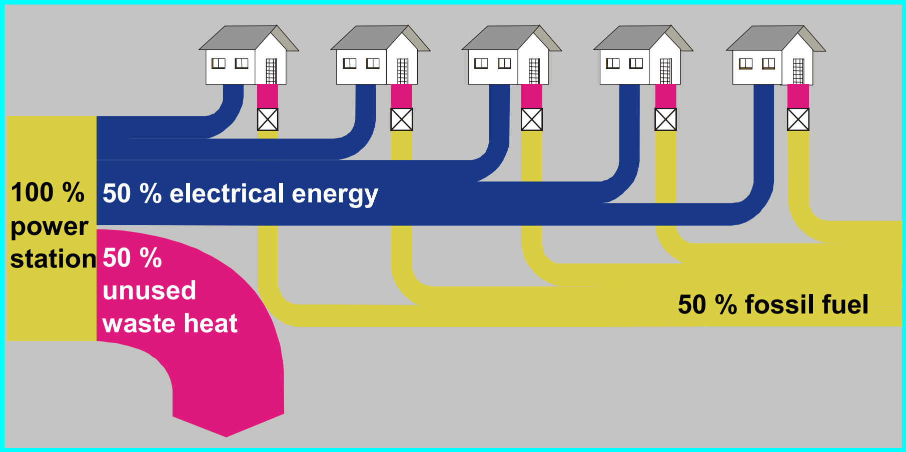
Interconnection of small, modular generation to low voltage distribution systems forms a new type of power system, **the Microgrid**.
Microgrids can be connected to the main power network or be operated islanded, in a coordinated, controlled way.

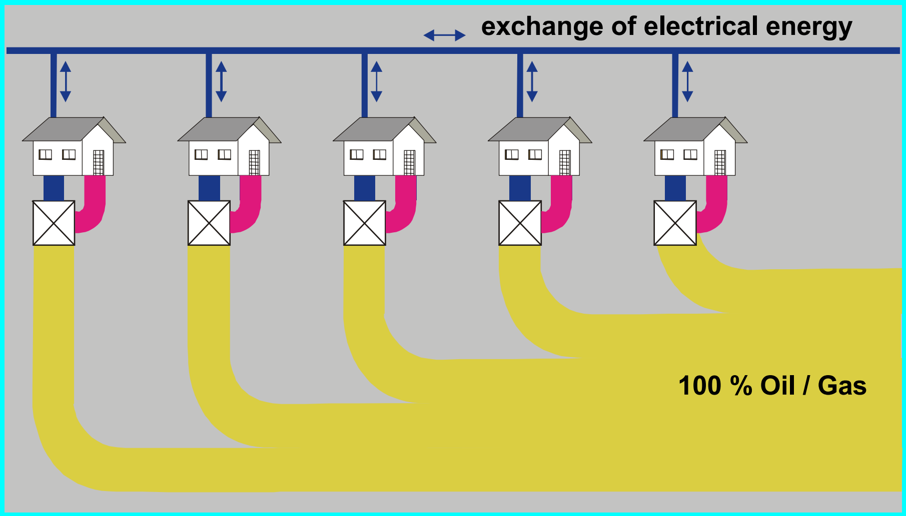


# Technical, economic and environmental benefits

- 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:

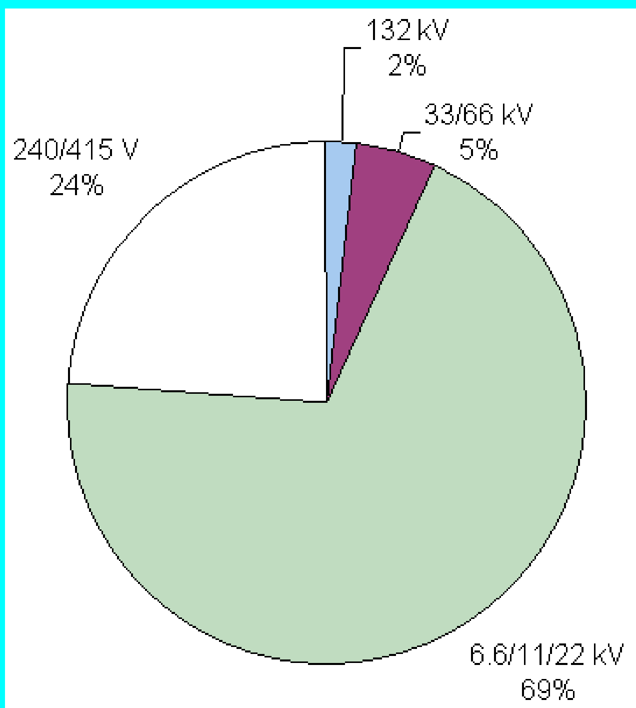
- Central power stations
- Decentral heat production

In Future:

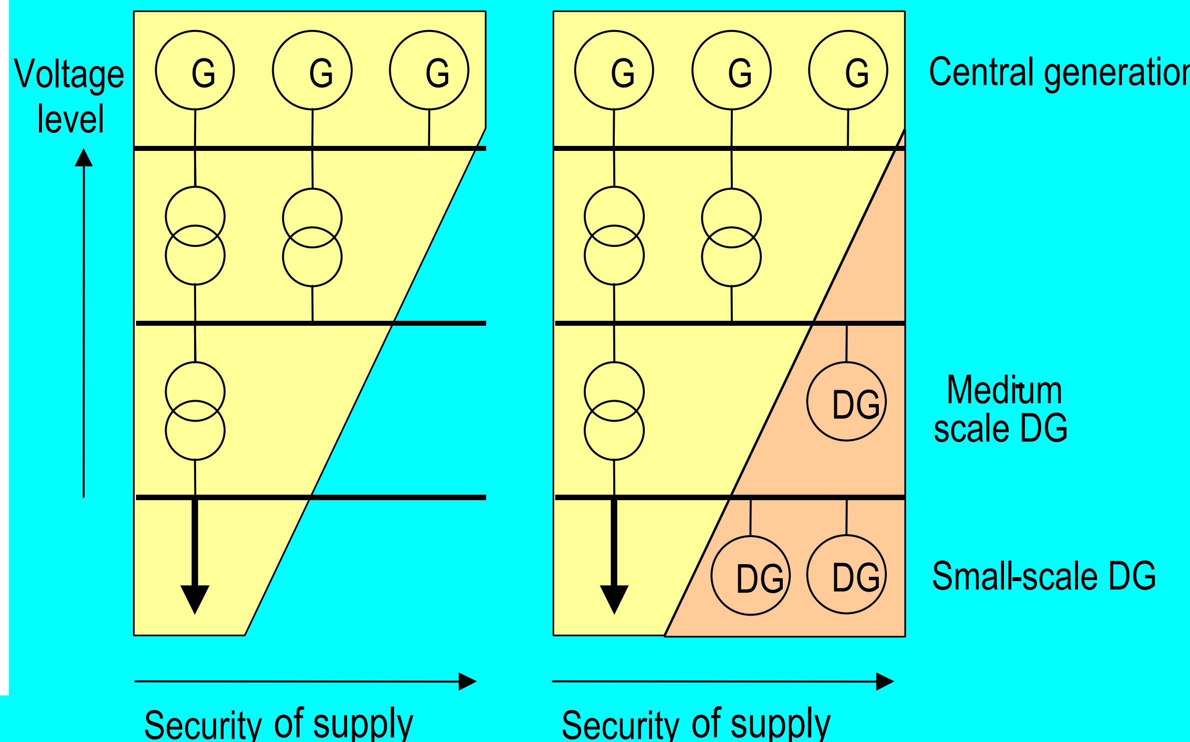
- Decentral combined heat and power

⇒ 1/3 less consumption of fossil sources of energy

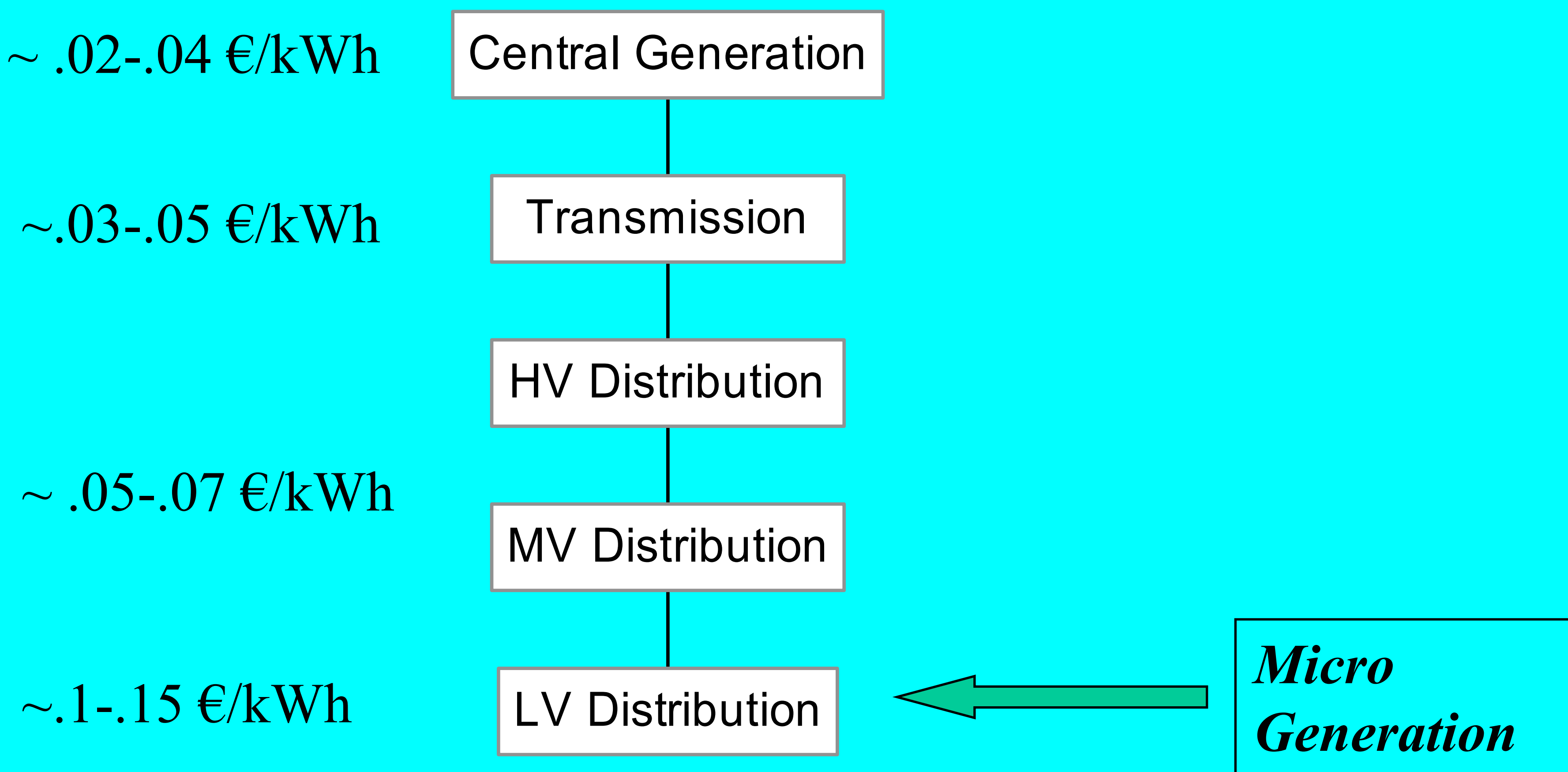
# Potential for DG to improve service quality




Distribution of CMLs



# Network Benefits –
## Value of Micro Generation



# 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 islanded and interconnected 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

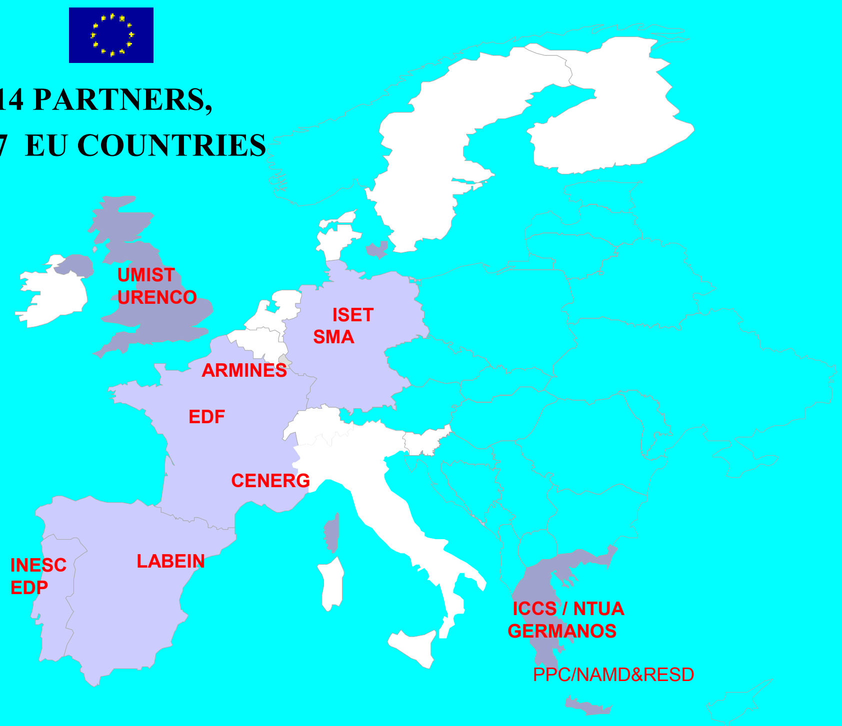
**GREAT BRITAIN**
- **UMIST**
- **URENCO**

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

**SPAIN**
- **LABEIN**

**NETHERLANDS**
- **EMforce**

**14 PARTNERS,**
**7 EU COUNTRIES**




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

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

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

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

CERTS, Berkeley 2005 Symposium on Microgrids, 17 June 2005

# R&D Objectives

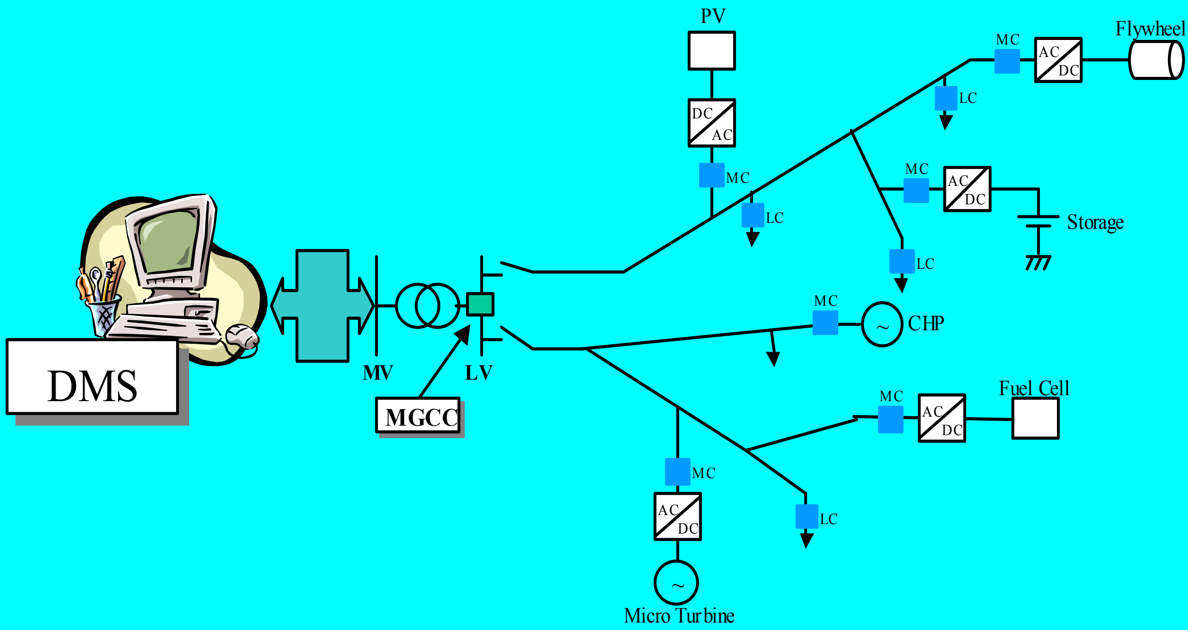
- Contribute to increase the share of renewables and to reduce GHG emissions;
- Study the operation of Microgrids in normal and islanding conditions;
- Optimize the operation of local generation sources;
- Develop and demonstrate control strategies to ensure efficient, reliable and economic operation;
- Simulate and demonstrate a Microgid 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 Highlights

- 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
- Steady State and Dynamic Analysis Tools

# Microgrids – Hierarchical Control

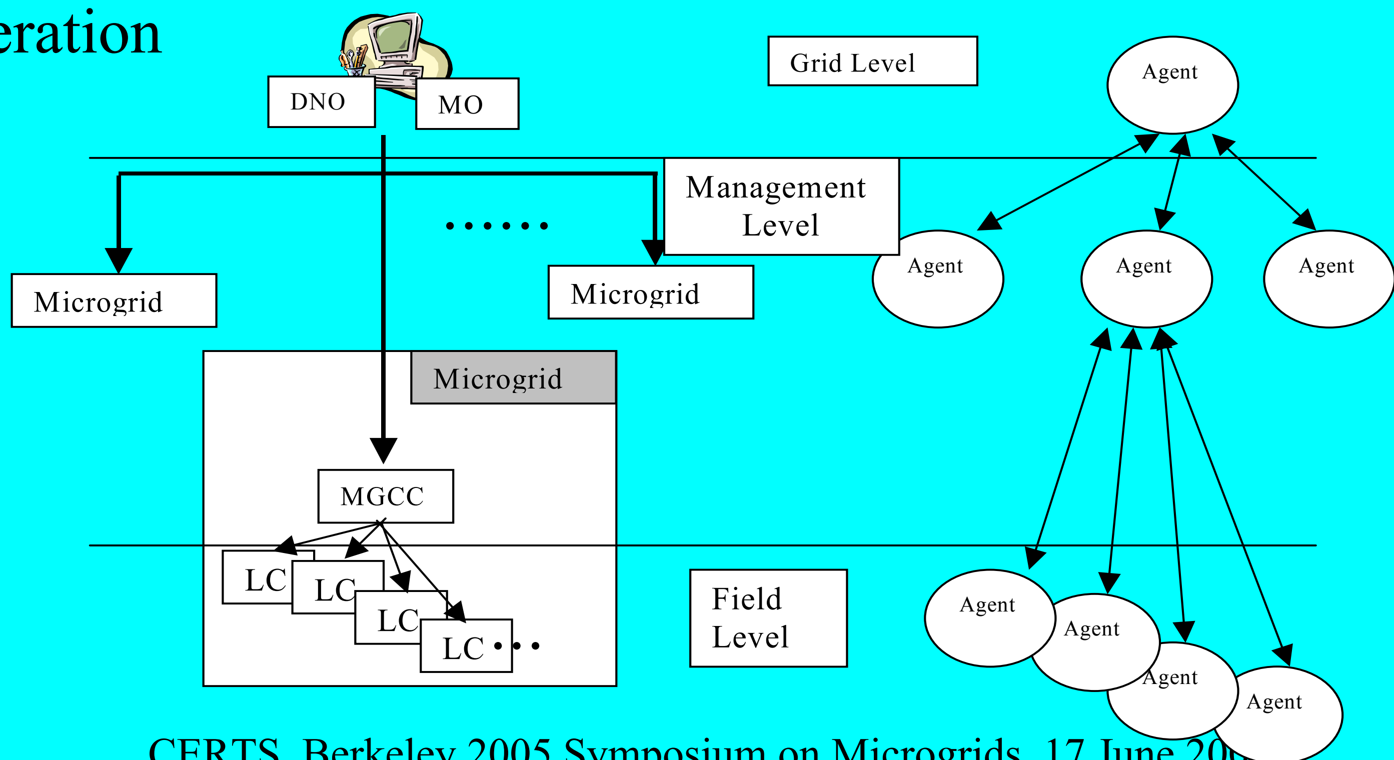
**MicroGrid Central Controller** (MGCC) promotes technical and economical operation, interface with loads and micro sources and **DMS;** provides set points or supervises LC and MC; **MC and LC Controllers**: interfaces to control interruptible loads and micro sources




Centralized vs. Decentralized Control

# MultiAgent System for Microgrids

- Autonomous Local Controllers
- Distributed Intelligence
- Reduced communication needs
- Open Architecture, Plug n' Play operation
- FIPA organization
- Java Based Platforms
- Agent Communication Language



# Participation of Microgrids in Energy Markets

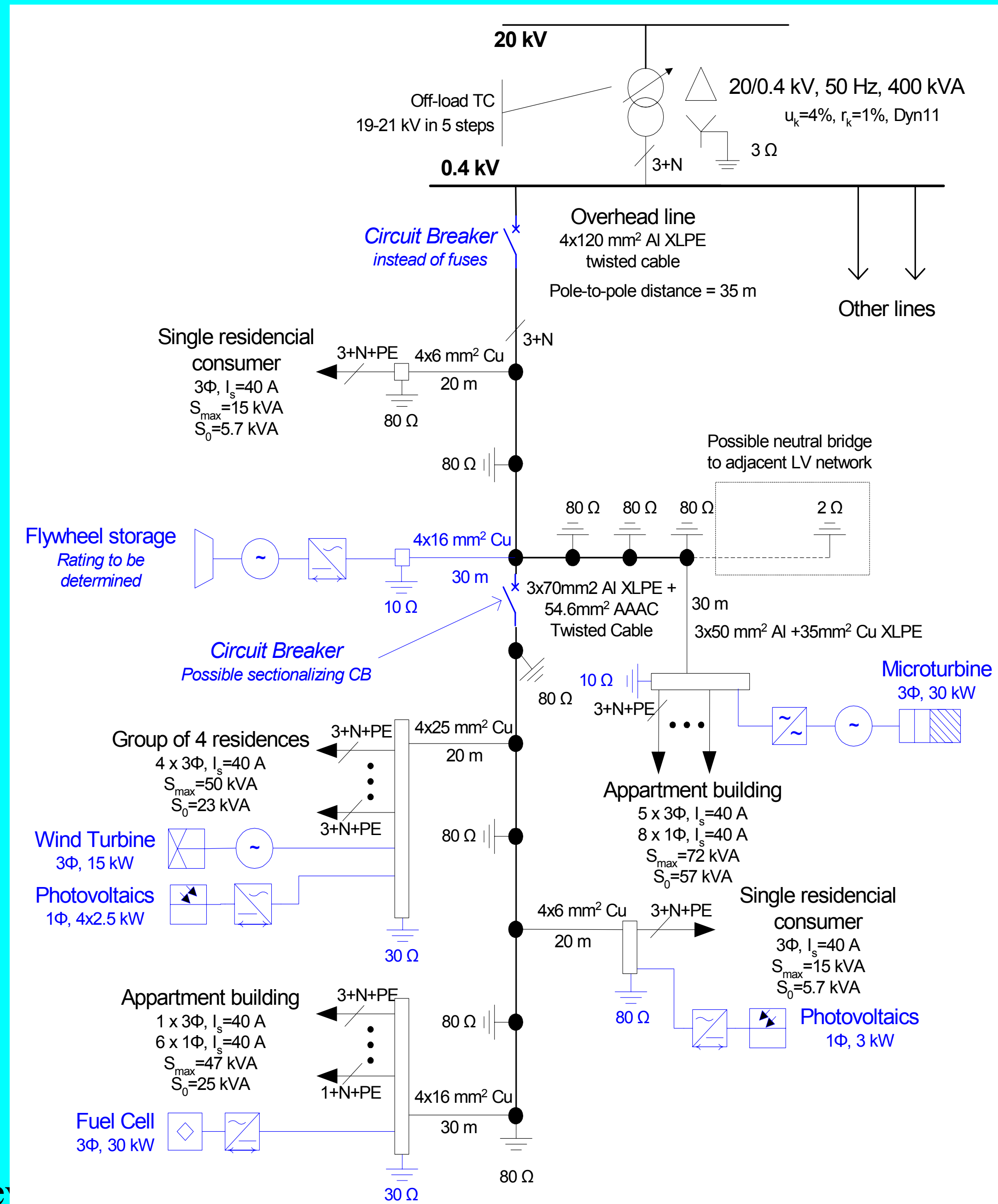
- Microgrid Serving its own needs using its local production, when financially beneficial **(Good Citizen)**

  MGCC minimises operation costs based on:
  - Prices in the open power market
  - Forecasted demand and renewable power production
  - Bids of the Microgrid producers and consumers.
  - Technical constraints

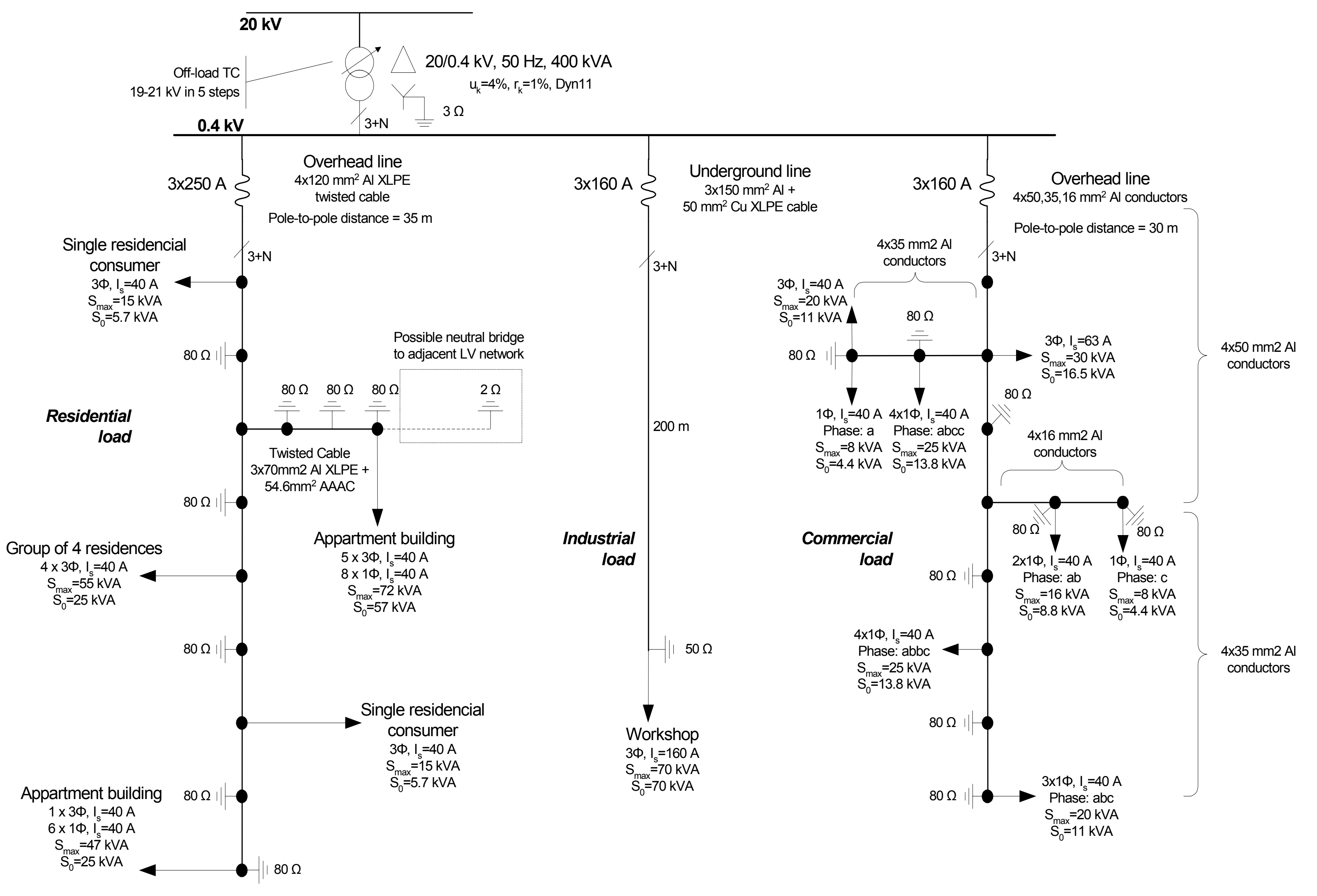
- Microgrid buys and sells power to the grid via an Energy Service provider **(Ideal Citizen)**

  MGCC maximizes value of the Microgrid, i.e. maximizes revenues by exchanging power with the grid based on similar inputs

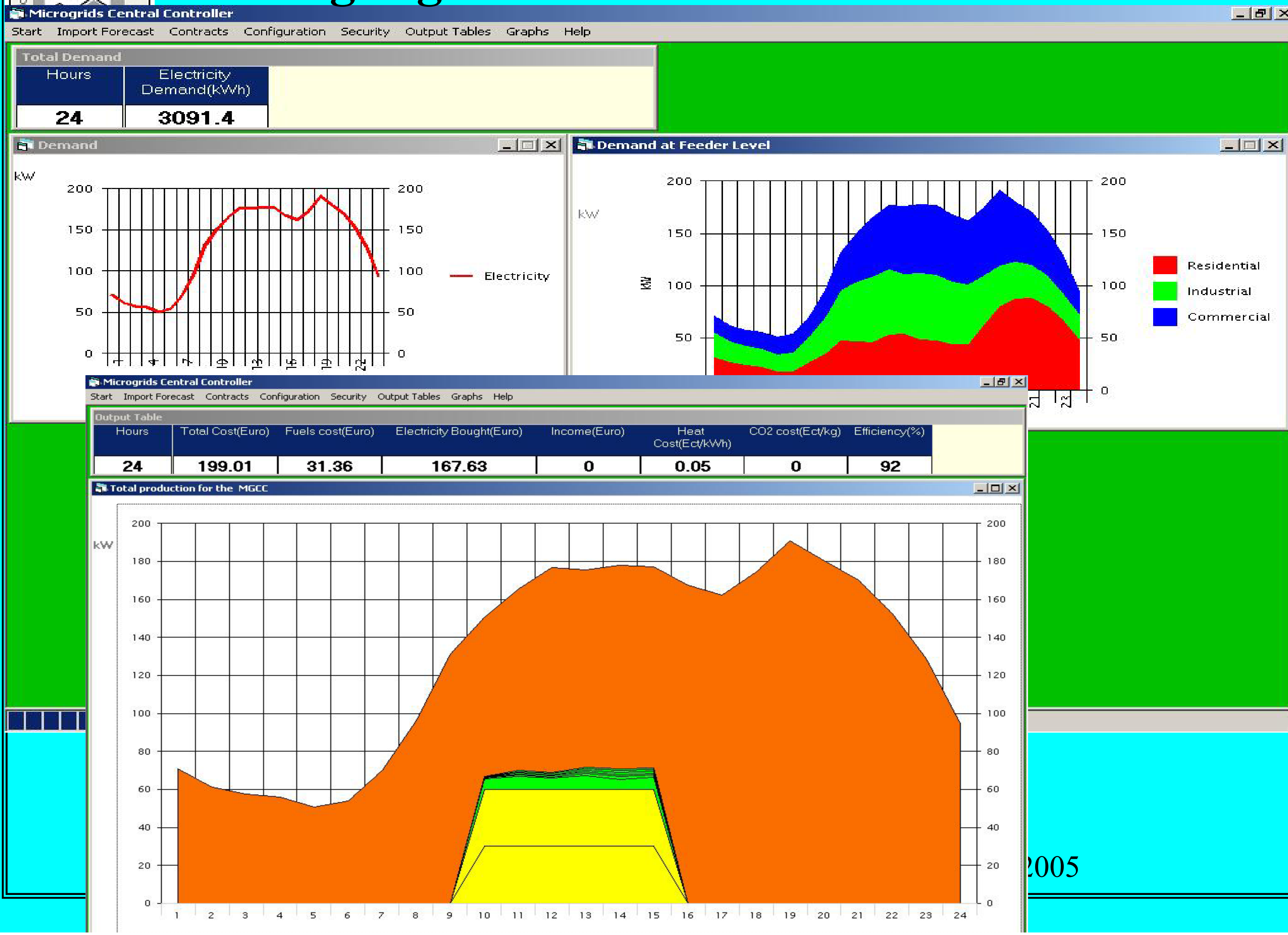
# Study Case LV Feeder with DG sources



# LV network with multiple feeders



# Highlight: MGCC Simulation Tool

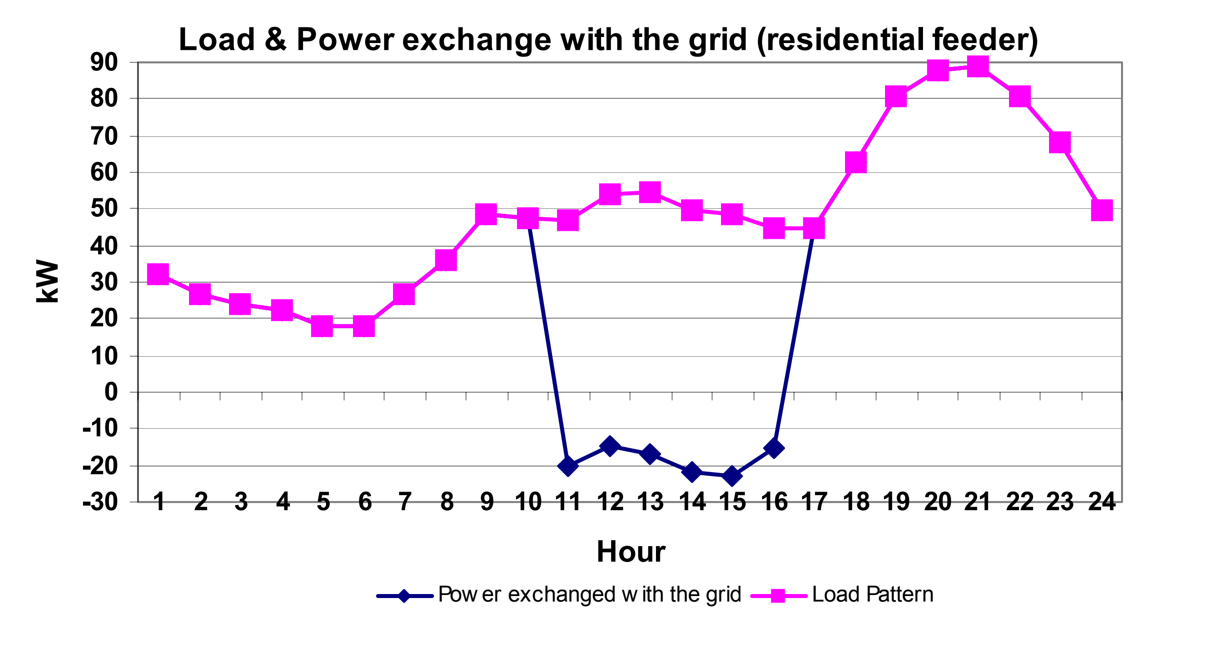


# Residential Feeder with DGs

Good Citizen Cost Reduction : 12.29 %

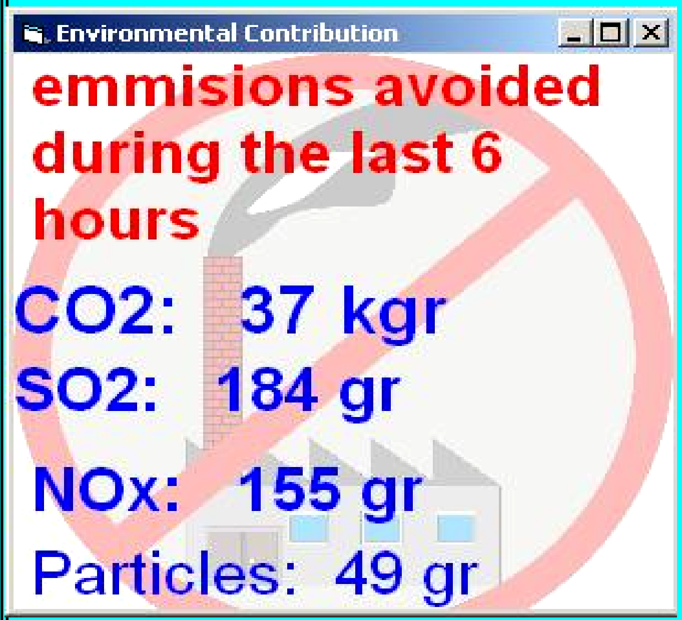
27% reduction in $CO_2$ emissions

Model Citizen Cost reduction : 18.66%



# Environmental Benefits

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




27% reduction in $CO_2$ emissions due to policy1

Maximum reduction in $CO_2$ emissions 548kgr/day- 22.11% higher cost

# 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 |

# Highlight: Reliability Assessment

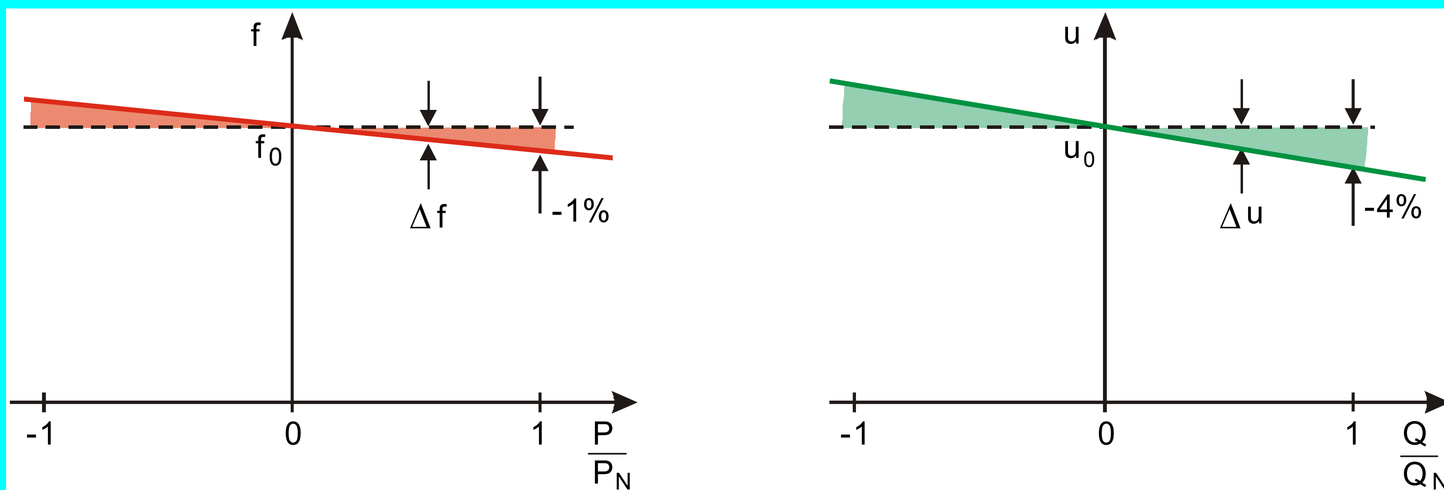
- System Maximum Load Demand: 188 kW
- Capacity of System Infeed: 210 kW (100%)
- Installed DGs: 15 kW Wind, 13 kW PVs, 30 kW Fuel Cells, 30 kW Microturbines

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

# Parallel operation of inverters

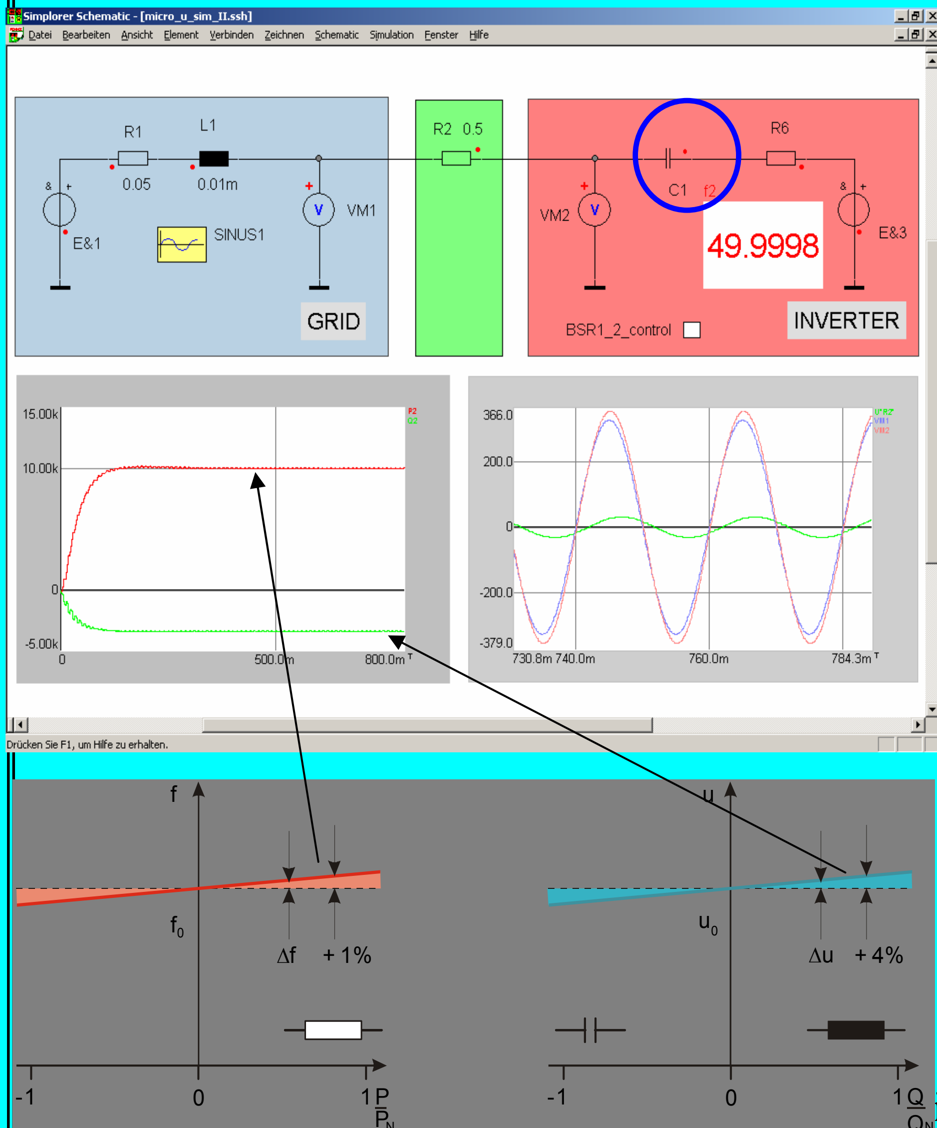



Frequency droop

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




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

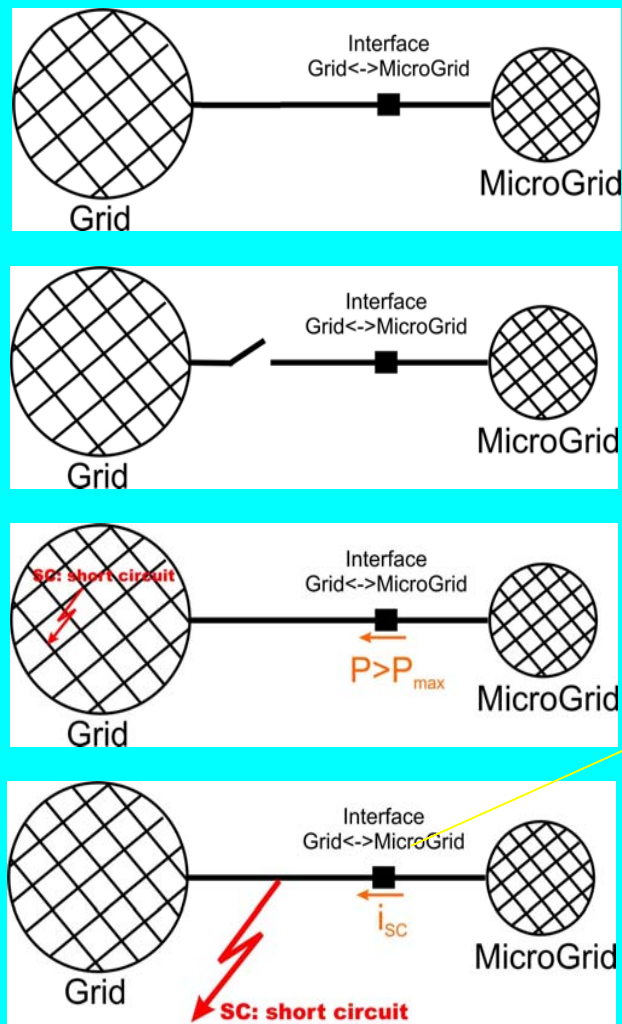
- **In a LV-grid components are coupled resistive, thus voltage determines the active power distribution**

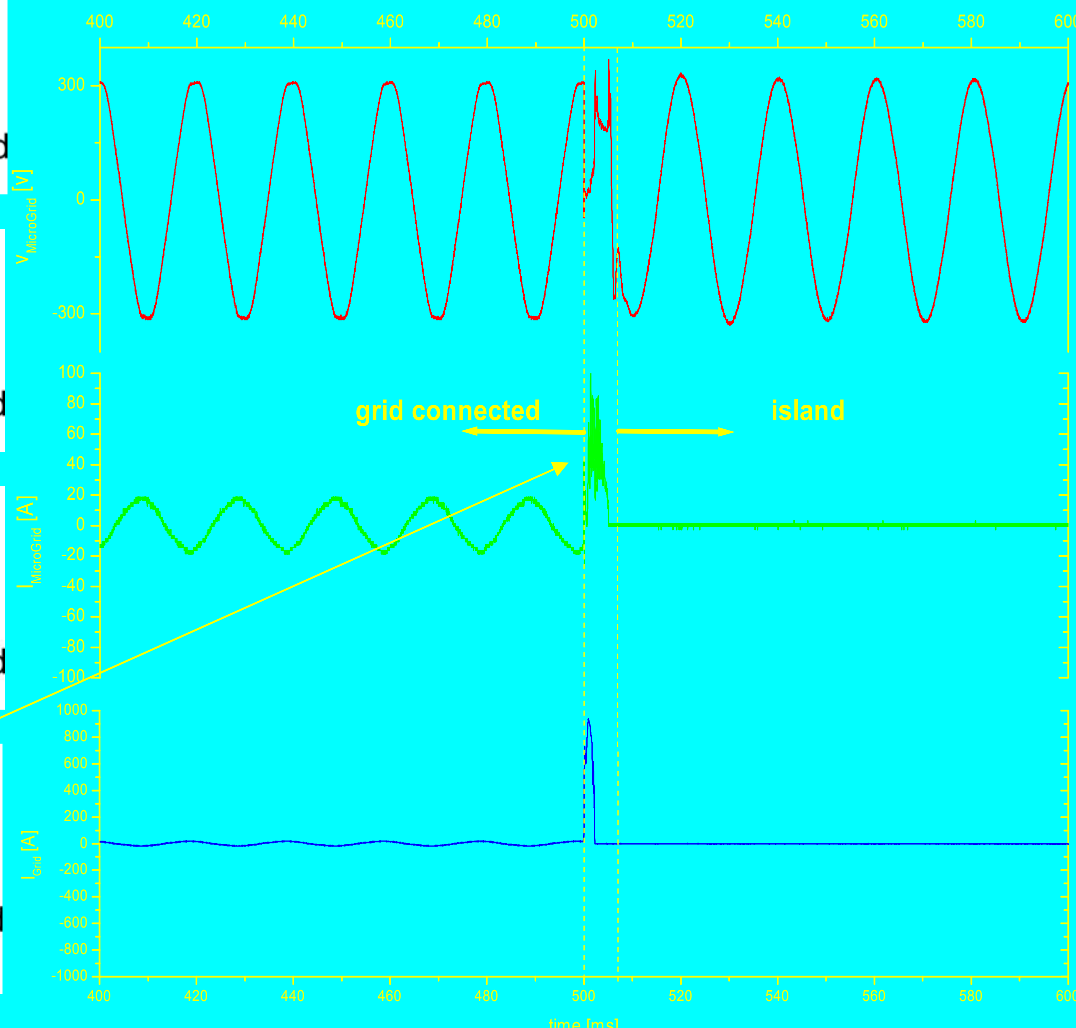
- **There are two effects of droops**
  - **direct (inductive coupling)**
  - **indirect (resistive coupling)**

- **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. Over-compensation has to be avoided!**

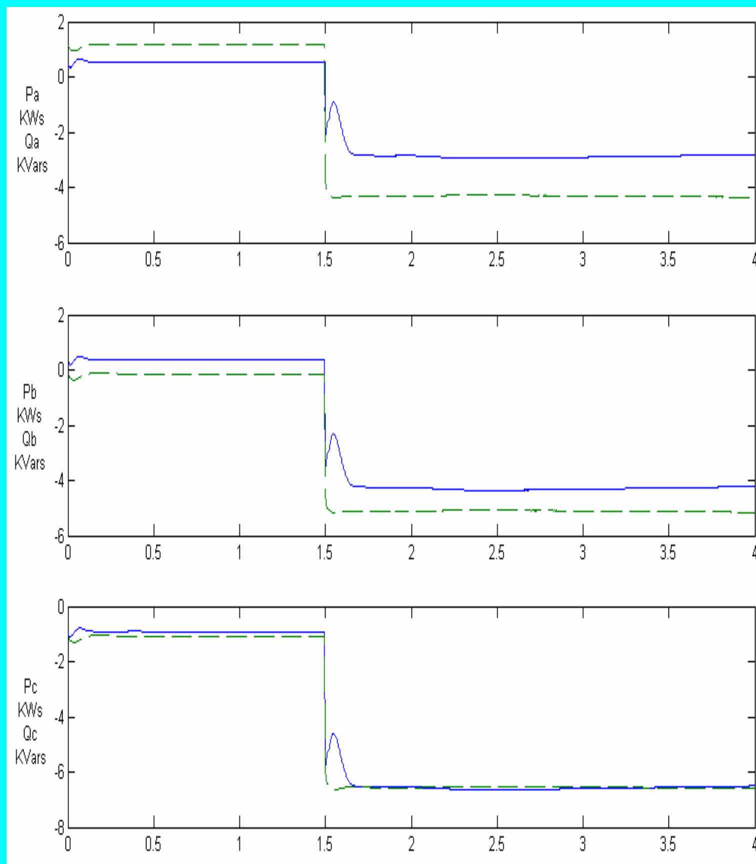
# Development of Electronic Switch



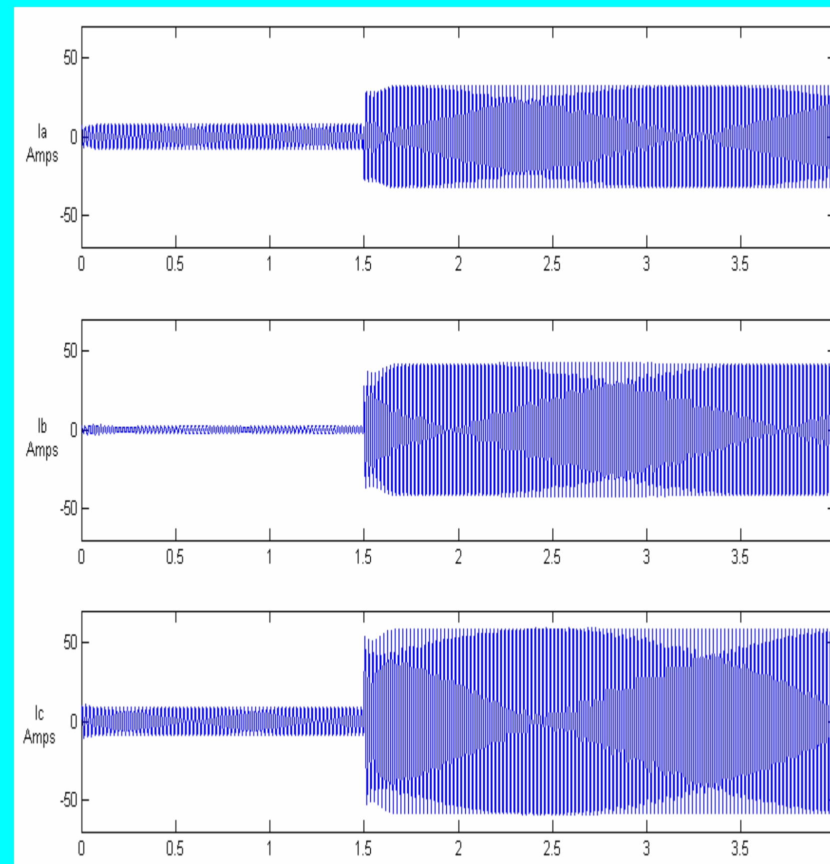



# Highlight: Modelling and Simulation

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




**P,Q per phase Battery Inverter A**




**I per phase Battery Inverter A**

# MORE MICROGRIDS

## Advanced Architectures and Control Concepts for More Microgrids

## Proposal/Contract no.: PL019864

**RESEARCH INSTITUTES & UNIVERSITIES (6)**

- ICCS/NTUA (GR)
- UMIST (UK)
- INESC Porto (PT)
- ISET (D)
- LABEIN (ES)
- ARMINES (F)

**MANUFACTURERS (8)**

- SIEMENS (D)
- ABB (S)
- SMA (D)
- EMforce (NL)
- GERMANOS (GR)
- ANCO (GR)
- ZIV (ES)
- I-Power (UK)

**UTILITIES & MICROGRID OPERATORS (7)**

- EDP (PT)
- CRES (GR)
- CONTINUON (NL)
- MVV (D)
- CESI (I)
- ELTRA (DE)
- LRPD (PL)

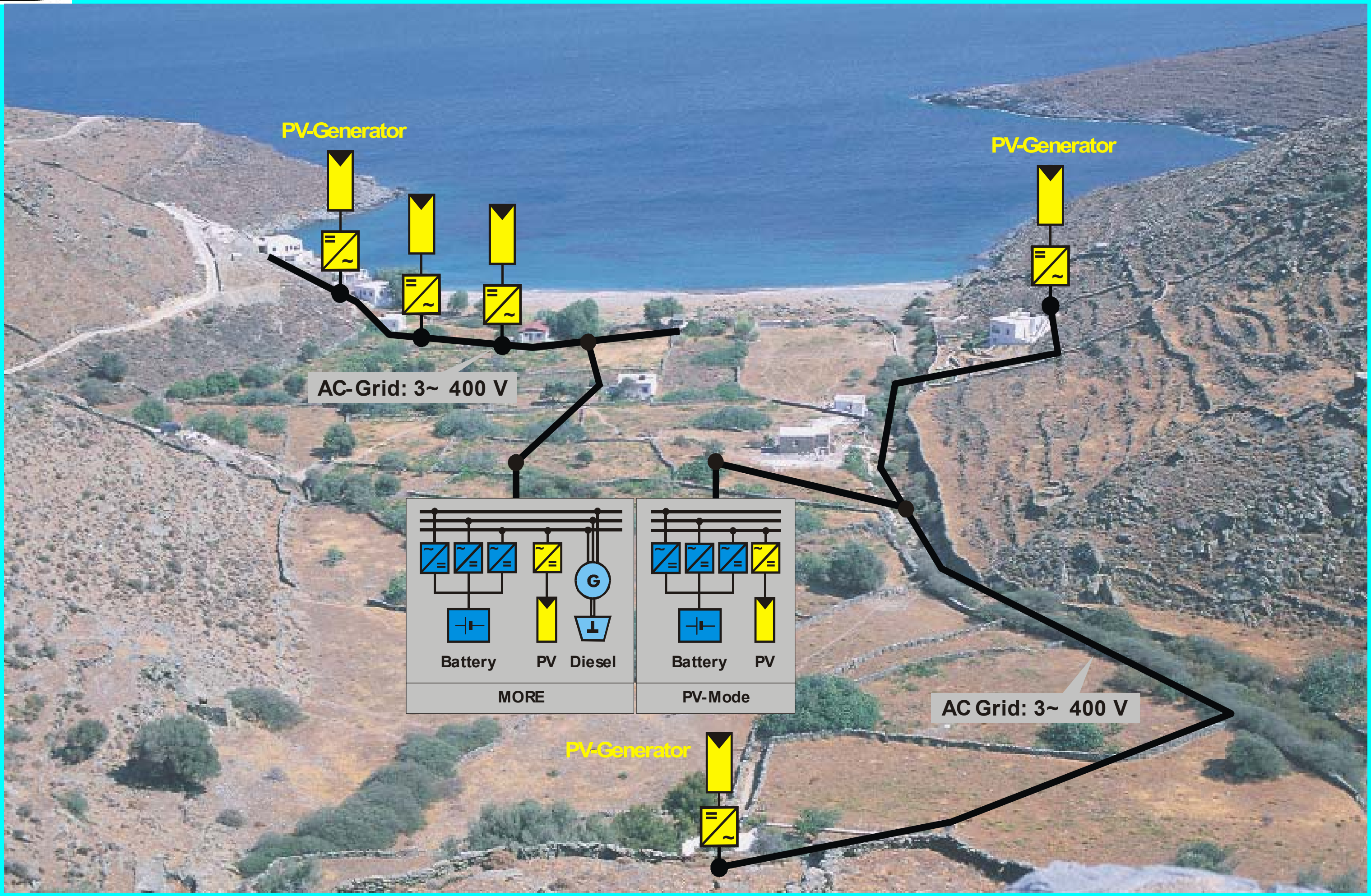
**Total Budget 7.9 M€**

**EC Contribution 4.5M€**

# MORE MICROGRIDS
# Workpackages

- WPA. Design of micro source and load controllers for efficient integration
- WPB. Development of Alternative Control Strategies (hierarchical vs. distributed) (emphasis on De-centralized – MAS technologies)
- WPC. Alternative Microgrids Designs
- WPD. Technical and Commercial Integration of Multi-Microgrids
- WPE. Standardization of Technical and Commercial Protocols and Hardware
- WPF. Field trials on actual Microgrids (7 Installations)
- WPG. Evaluation of the system performance on power system operation (Germany, Italy, Denmark, Netherlands, UK, Portugal, Greece, Poland…)
- WPH. Impact on the Development of Electricity Infrastructures (expansion Planning) (Germany, Italy, Denmark, Netherlands, UK, Portugal, Greece, Poland…)

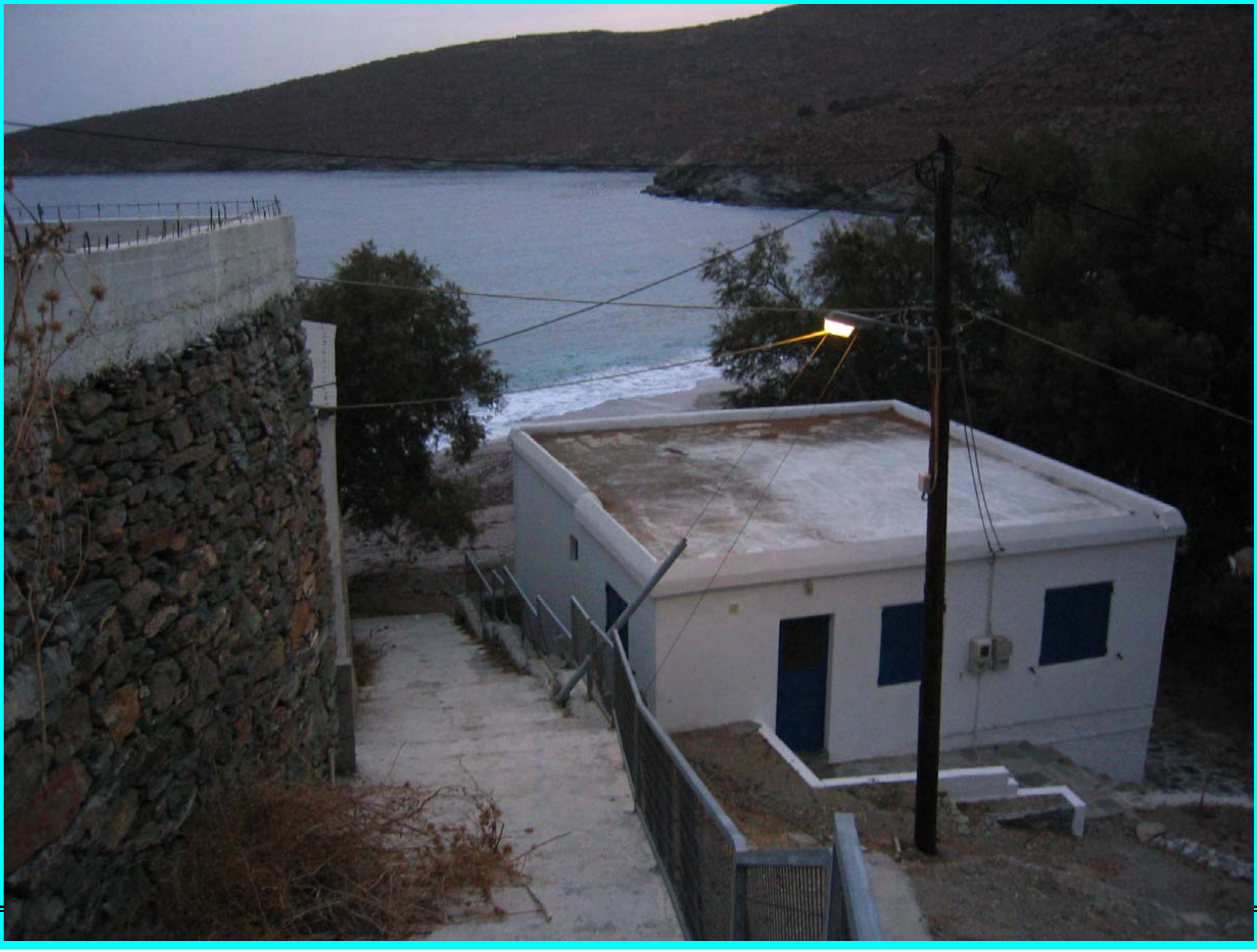
# Pilot Kythnos Plant




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

# The Kythnos Microgrid

# The Kythnos Microgrid



# 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 Field Testing and Benefits Quantification

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