Security of Supply and Power Quality through DER

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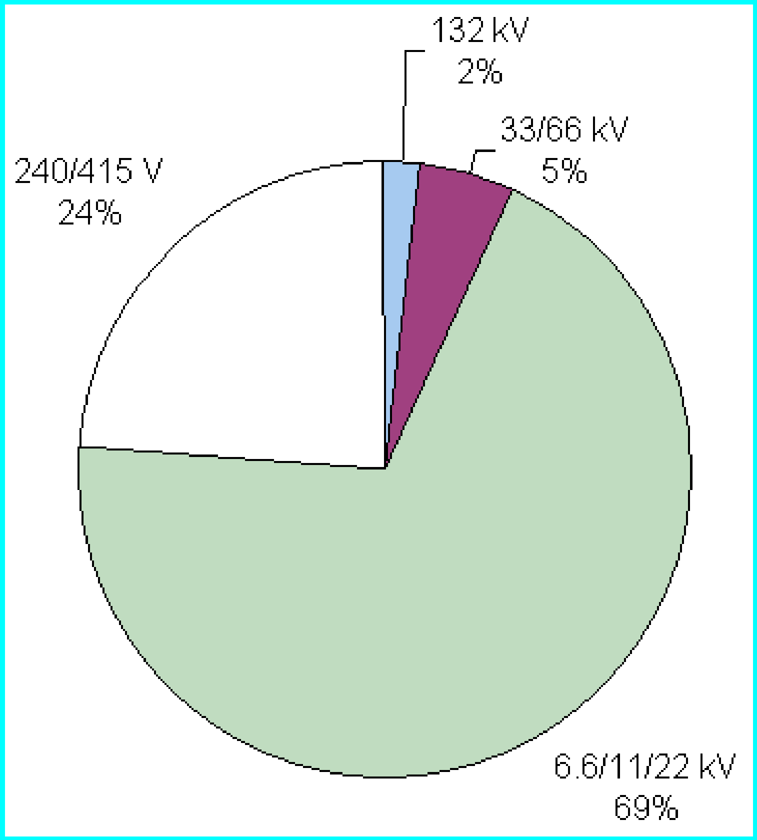
Technical, economic and environmental benefits of DER

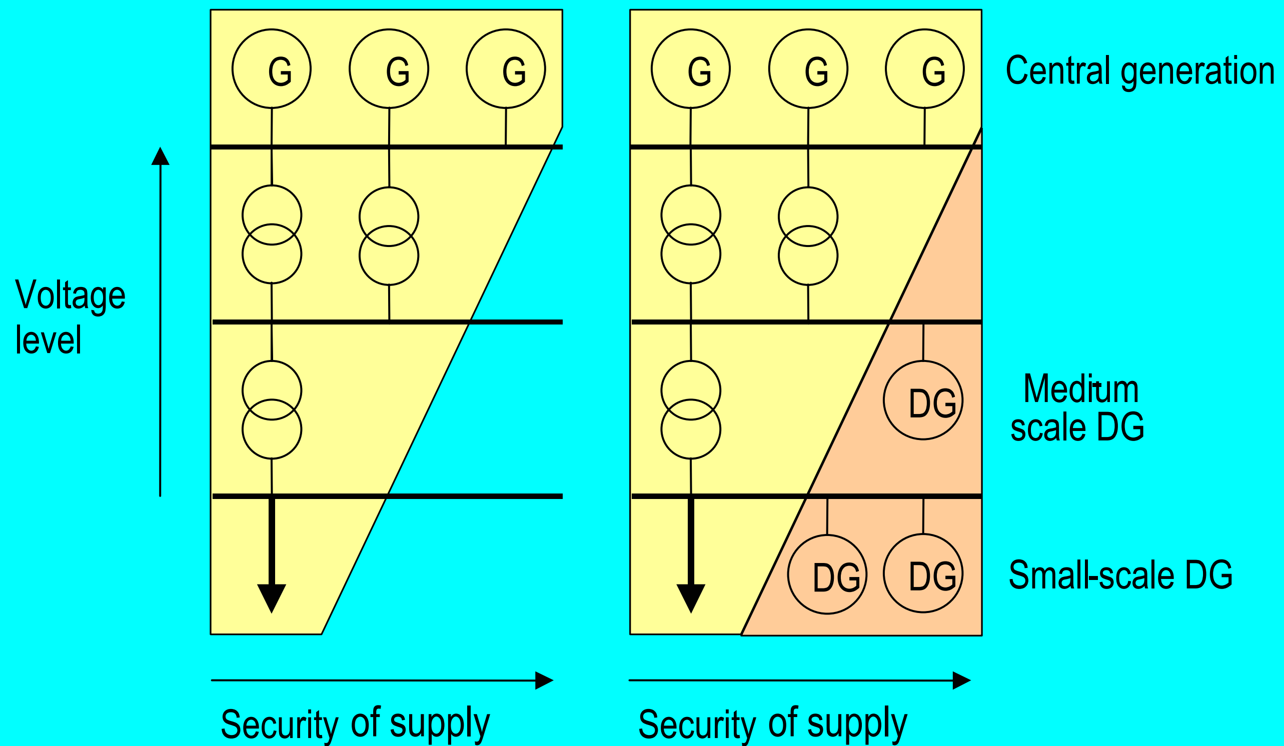
- Energy efficiency
- Minimisation of the overall energy consumption
- Improved environmental impact
- Improvement of energy system reliability and quality of service
- Network benefits
- Cost efficient electricity infrastructure replacement strategies

Improvement of Reliability

Distribution of CMLs



Potential for DG to improve service quality



Cost of Power Outages for Selected Commercial Customers

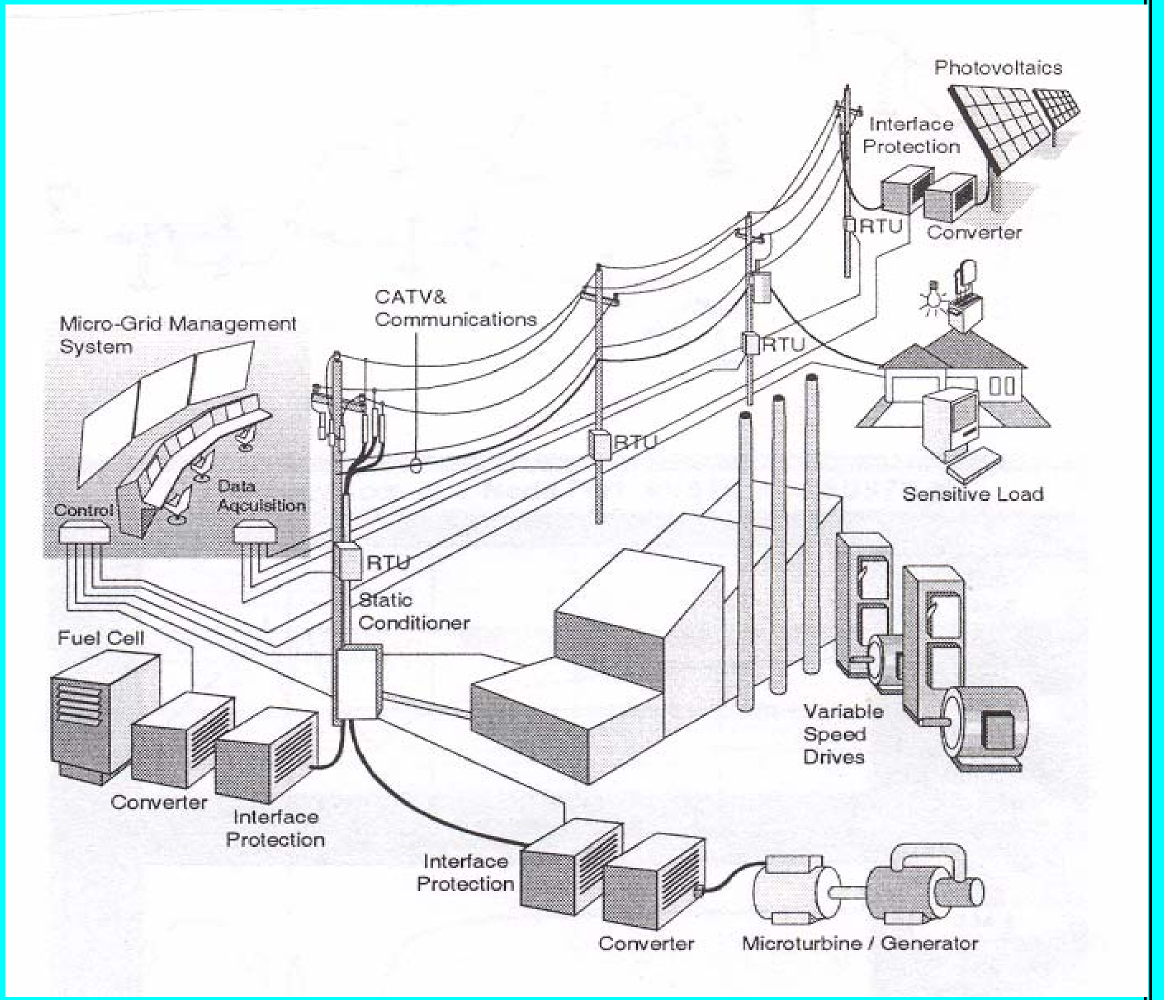
- Brokerage Operations $6,480,000 per hour
- Credit Card Operations $2,580,000 per hour
- Airline Reservations $90,000 per hour
- Telephone Ticket Sales $72,000 per hour
- Cellular Communications $41,000 per hour

Source: “Reliability and Distributed Generation”, a White Paper by Arthur D. Little

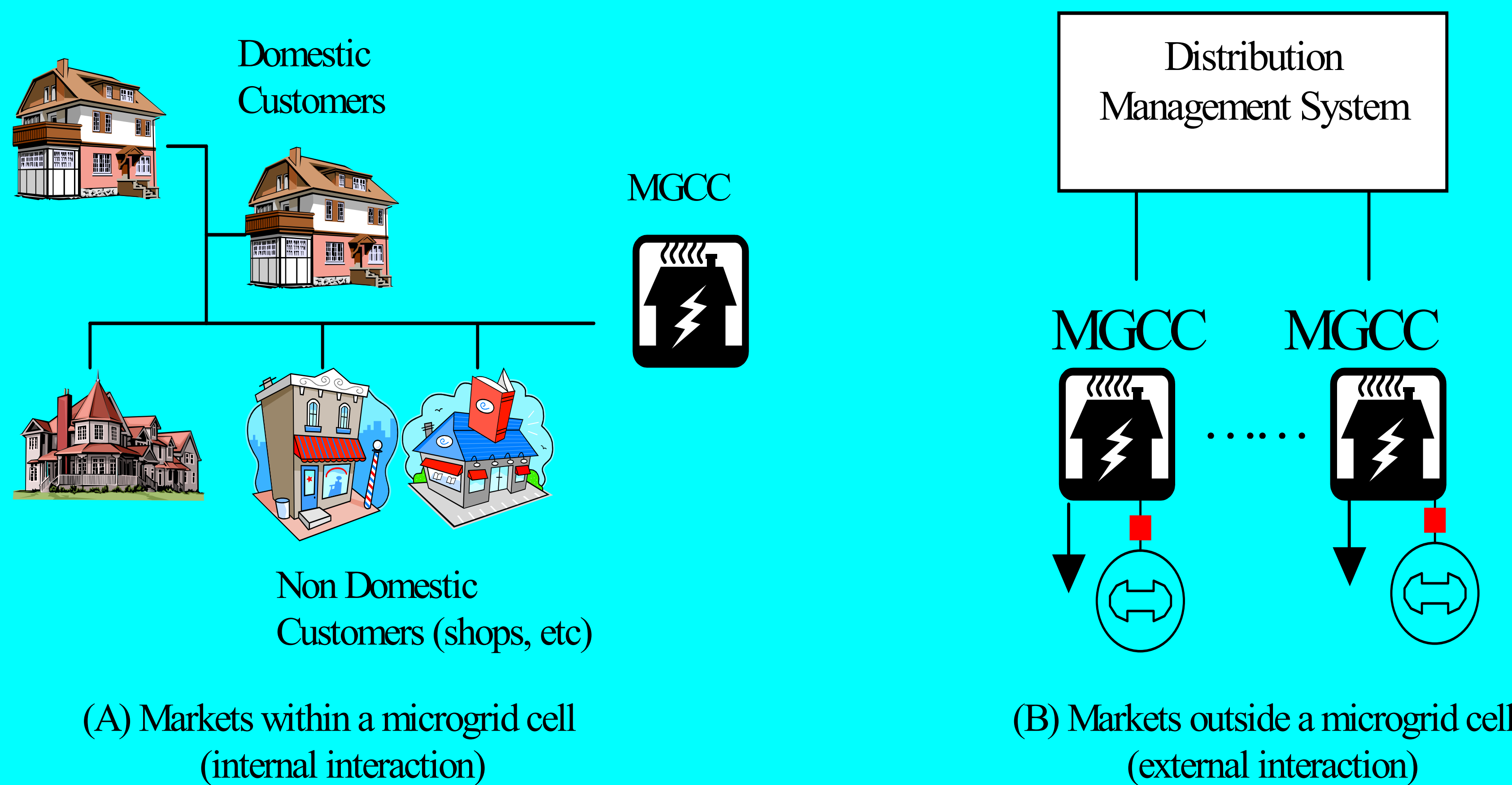
MICROGRIDS - Maximizing DER benefits

Interconnection of small, modular generation, storage and controllable load to low voltage distribution systems form **Microgrids** .

Microgrids can be connected to the main power network or be operated autonomously, similar to power systems of physical islands.

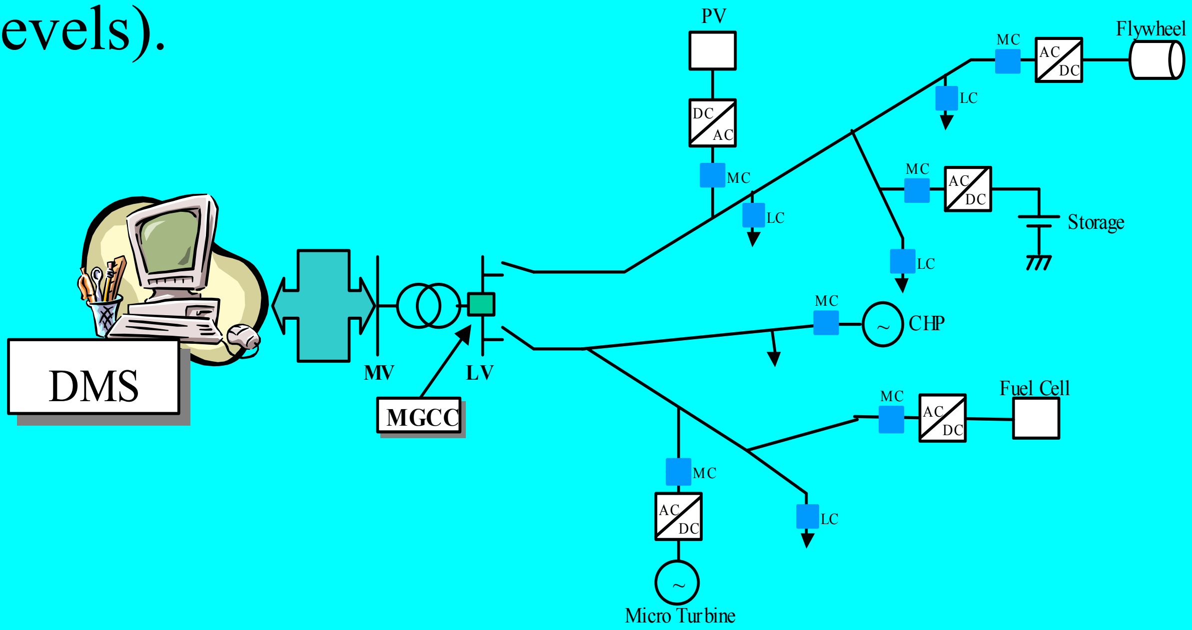


Internal and External Markets



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 inject in the MV grid;
    - In this case, the MGCC:
      - Interfaces with MC, LC and DMS;
      - Optimizes operation (economic scheduling, forecasting, DSM functions, Security assessment…);

Islanded Operation

Improved reliability and resilience

- 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, 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,…);
      - Adjusts Microgrid voltage and frequency to ensure seamless reconnection
      - Eventually, triggers black start functions.

MICROGRIDS Project

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

Contract : ENK5-CT-2002-00610

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

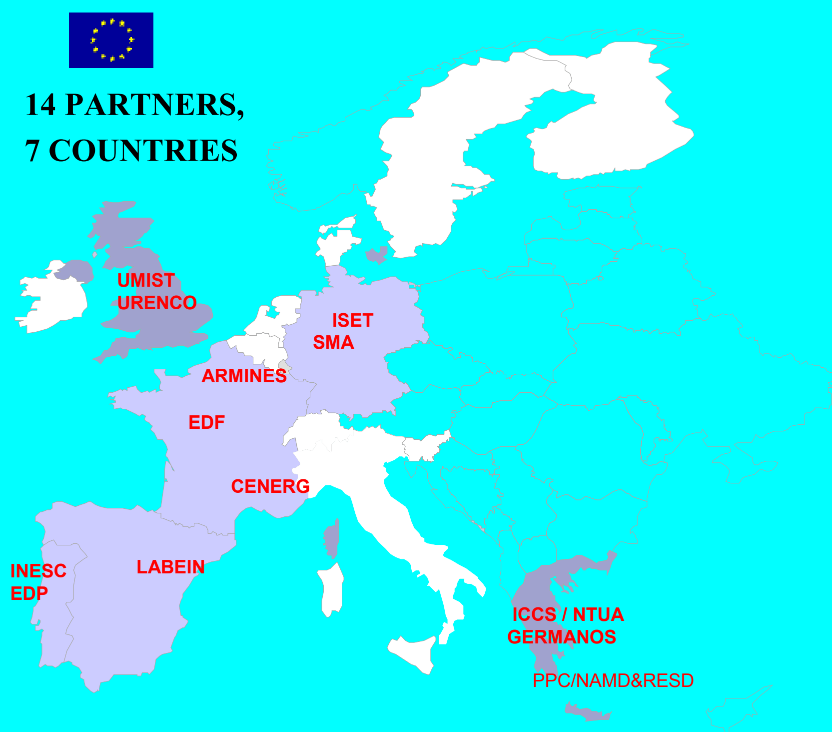
PORTUGAL
- **EDP**
- **INESC**

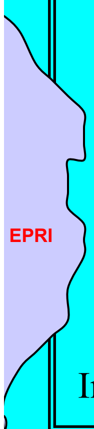
SPAIN
- **LABEIN**

NETHERLANDS
- **EMforce**

USA
- **EPRI**

14 PARTNERS,
7 COUNTRIES





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

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

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

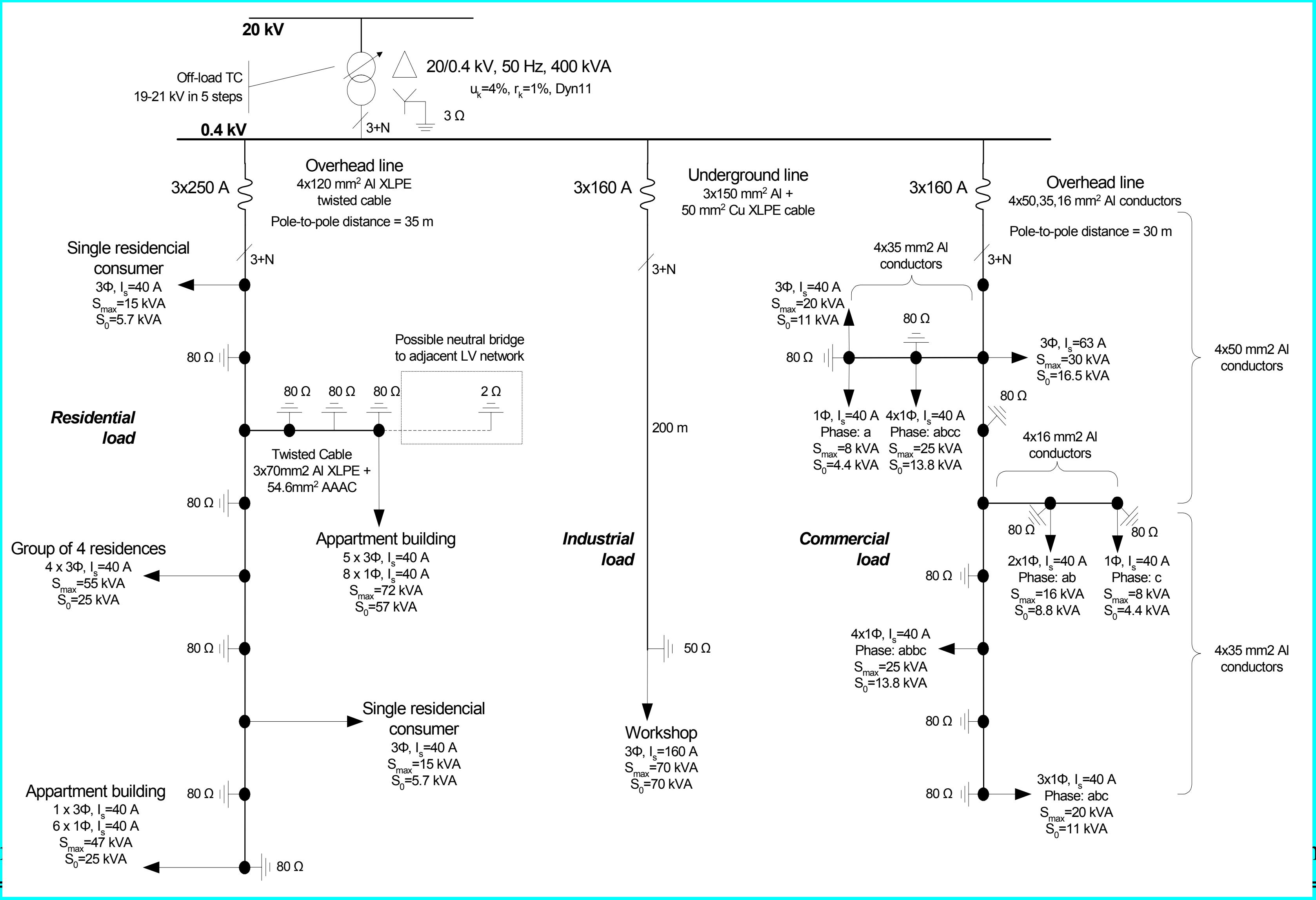
http://microgrids.power.ece.ntua.gr

MICROGRIDS Highlight 1:

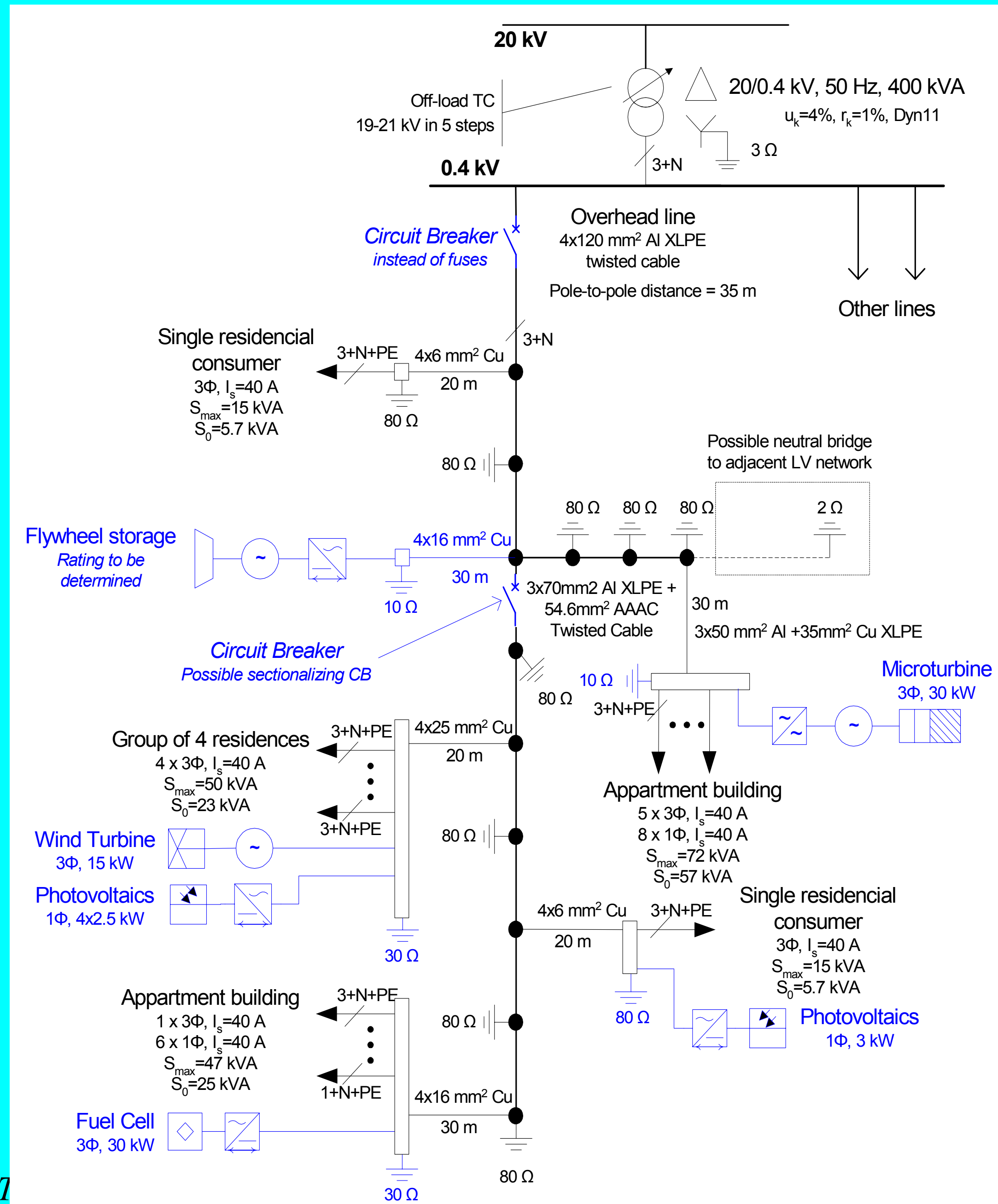
Permissible expenditure to enable islanding

Customer Sector:		Residential	Commercial
Annual benefit	=	2 €/kW_{pk}	25 €/kW_{pk}
Net present value	=	20 €/kW_{pk}	250 €/kW_{pk}
Peak demand	=	2 kW	1000 kW
Perm. expenditure	=	€40	€250,000
MicroGrid (2,000kW)		€40,000	€500,000

LV network with three feeders



Study Case LV Feeder with DG sources



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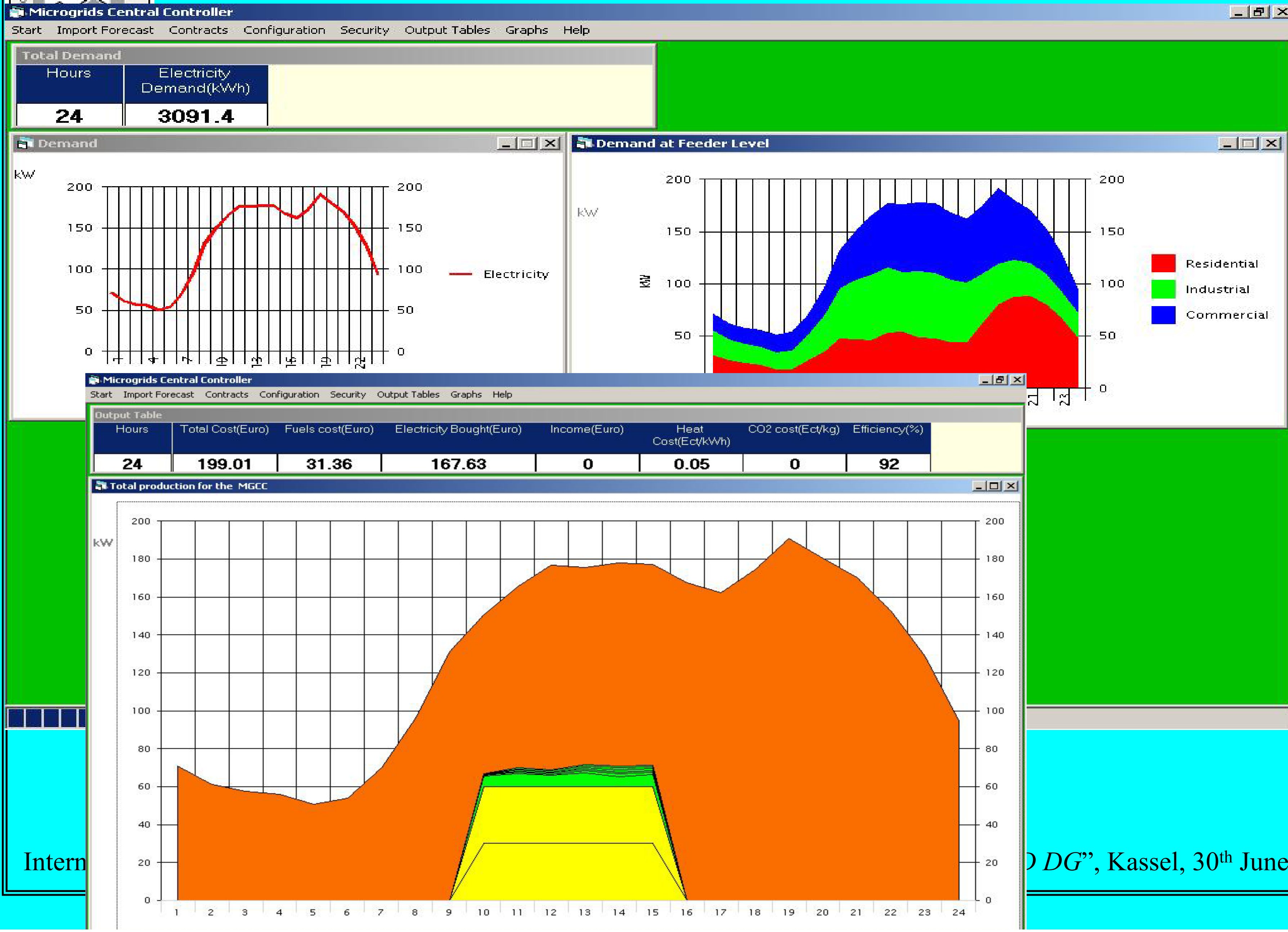
MICROGRIDS Highlight 2

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

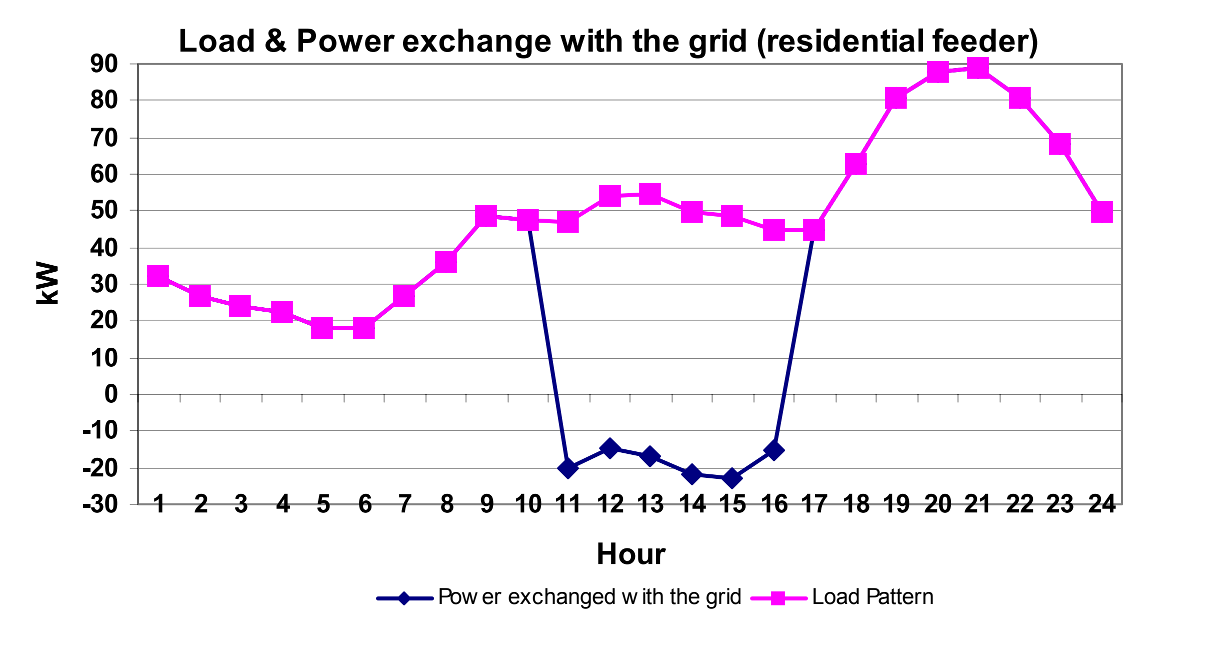
Highlight: MGCC Simulation Tool



Residential Feeder with DGs

Good Citizen Cost Reduction : 12.29 %

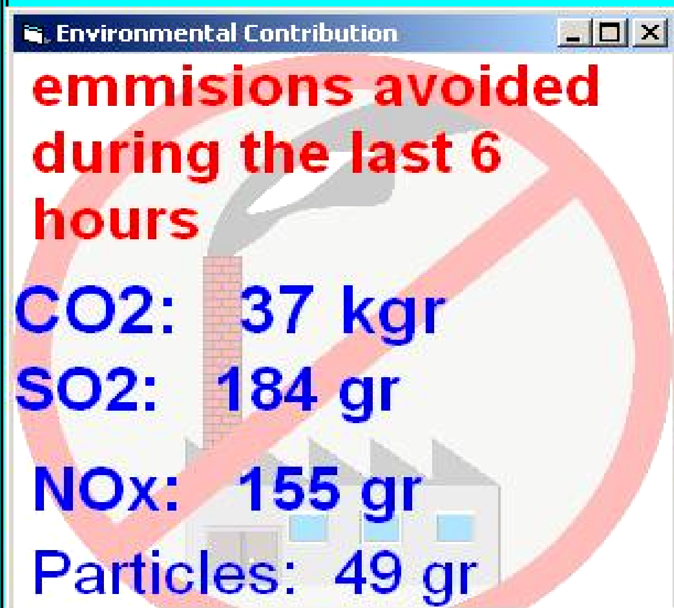
Ideal Citizen Cost reduction : 18.66%



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.



27% reduction in CO_2 emissions due to policy1

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

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

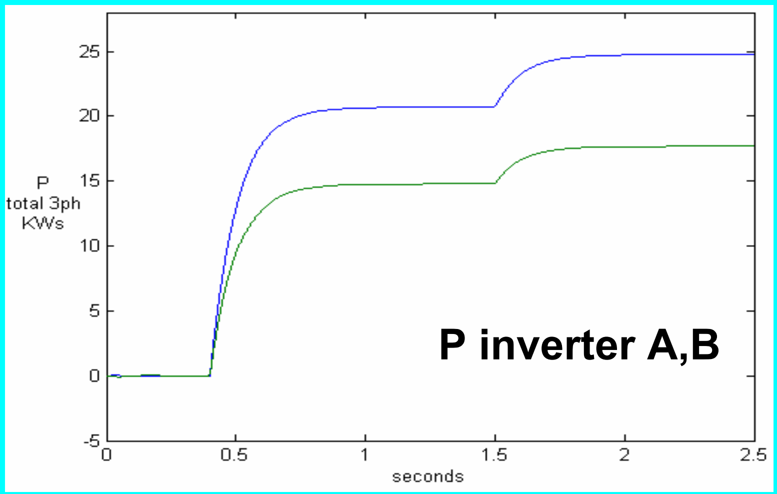
Reliability Assessment – continued

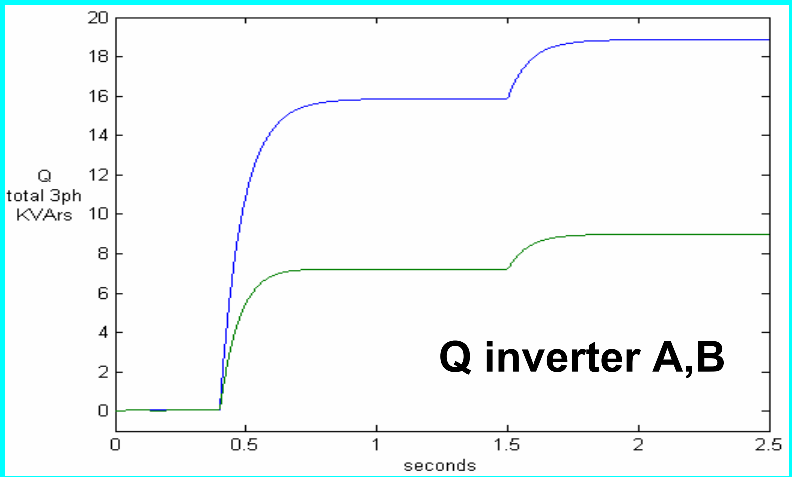
	FLOL (ev/yr)	LOLE (hrs/yr)	LOEE (kWh/yr)
Infeed Capacity 90% (no microsources)	8,52	31,08	2313,77
Infeed Capacity 90%, system load 207 kW (+10%) (no microsources)	44,10	92,75	3073,84
Infeed Capacity 90%, load 207 kW (with Wind + PV)	11,35	36,69	2232,54
Infeed Capacity 90%, load 207 kW (all microsources)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

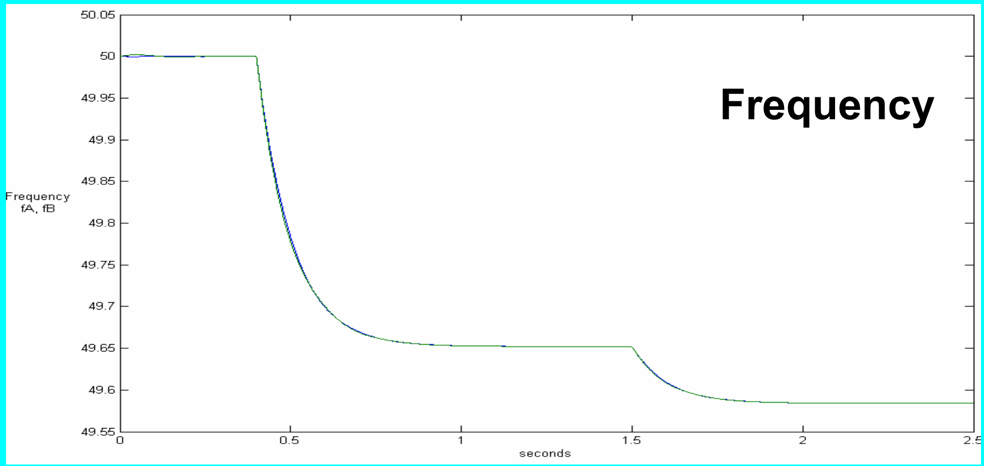
MICROGRIDS Highlight 4: Simulation Tool

- **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 the “stator transients”.
- Lines with **any X/R ratio** can be handled.
- **Radial and non-radial** network topologies can be handled.
- All basic **neutral earthing schemes** can be represented (TN, TT, IT).
- **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**.

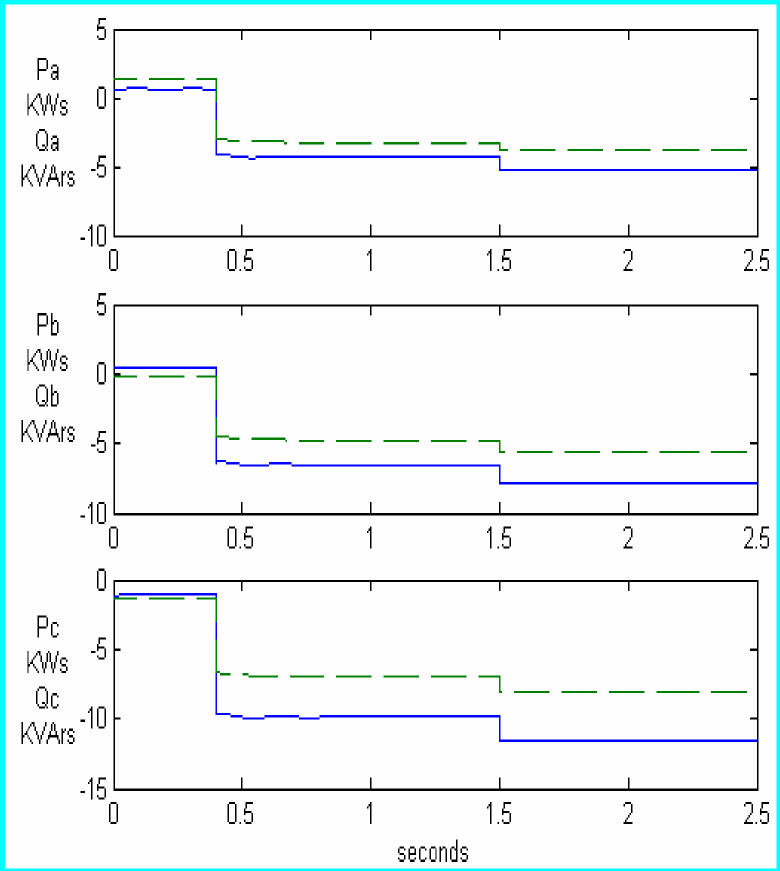
Two battery inverters - Isolation from grid + load increase



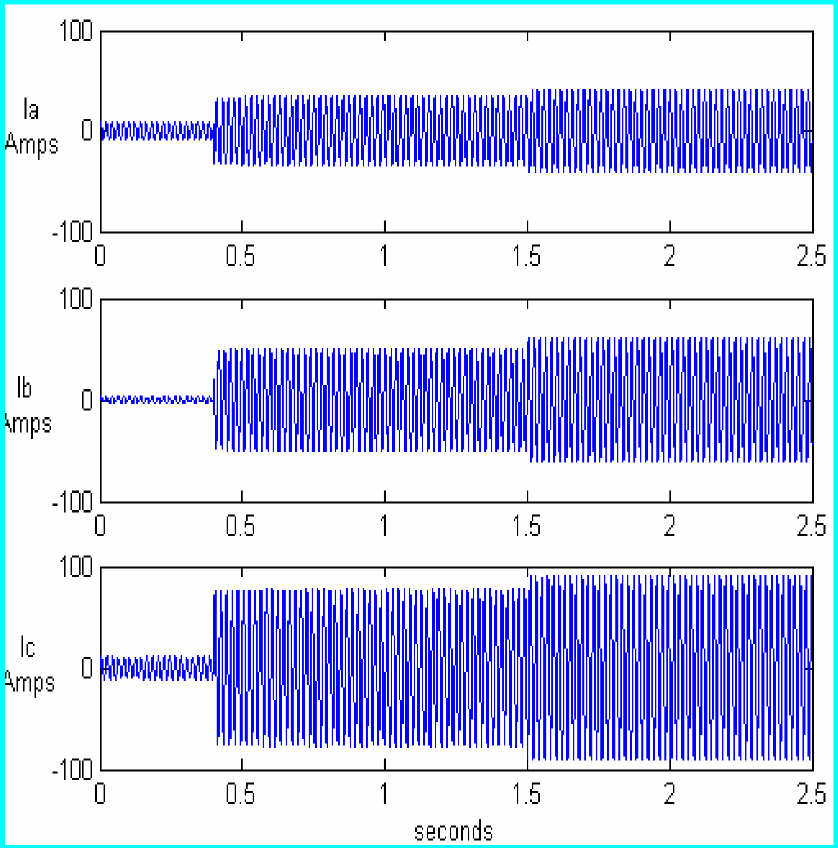




Study Case B
Two battery inverters - Isolation from grid + load increase



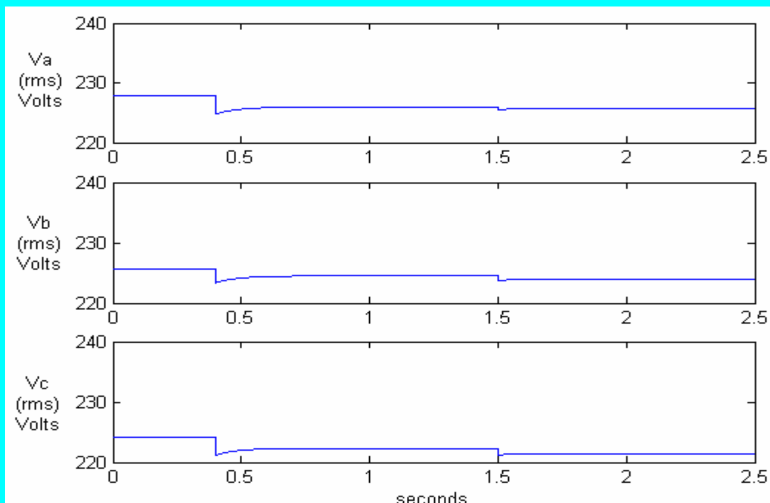
P,Q per phase inverter A



I per phase inverter A

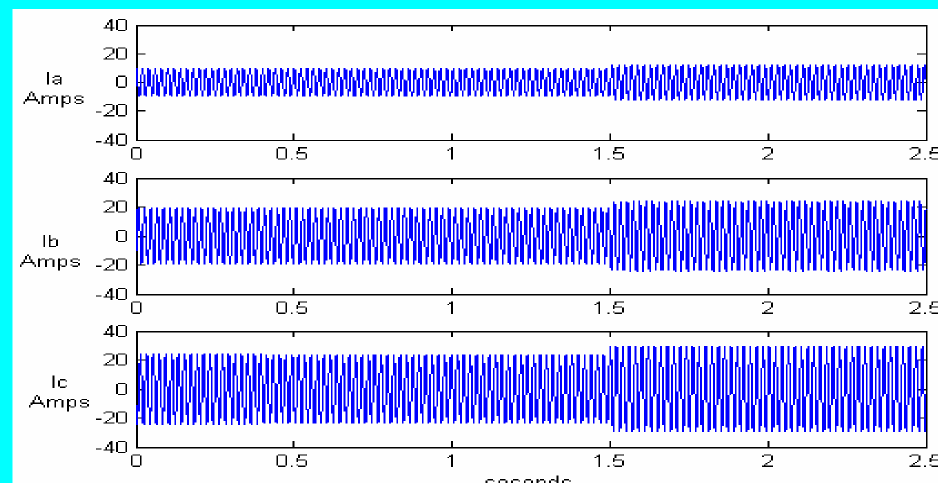
Study Case B

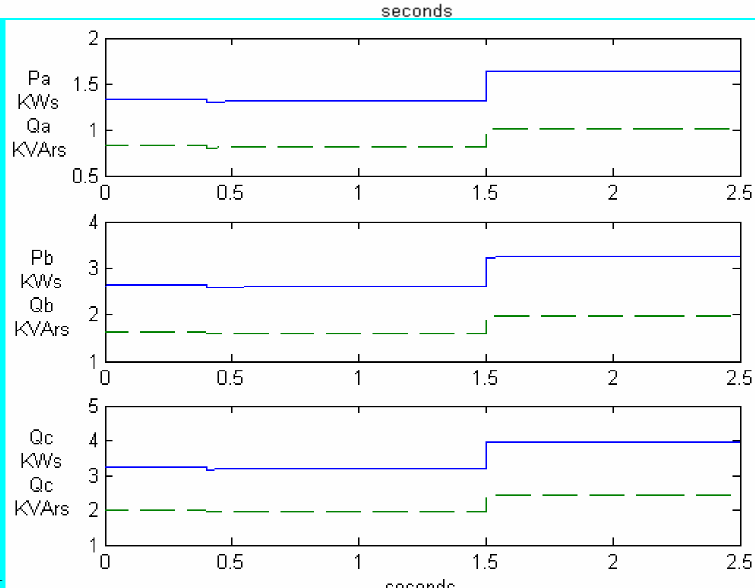
Two battery inverters - Isolation from grid + load increase



V per phase - Node C

I per phase Node C





P,Q per phase Node C

OPEN QUESTIONS

- Security of Supply (quantification)
  - Can DG provide generation security of supply (forget network)
    - Can DG displace conventional generation? Can we rely on wind
    - Can we retire conventional plant because we have DG?
  - Can DG provide system support (ancillary services), frequency , flow and voltage control
  - Can DG contribute to network security (blackouts occur because of faults on Transmission)
- EU T&D replacement policies (quantification)
  - What is the role of DG in T&D reinforcement and replacement policies

Thank you for your attention!

HAPPY BIRTHDAY PROFESSOR SCHMID