INTELLIGENT CONTROL OF DISTRIBUTED ENERGY RESOURCES

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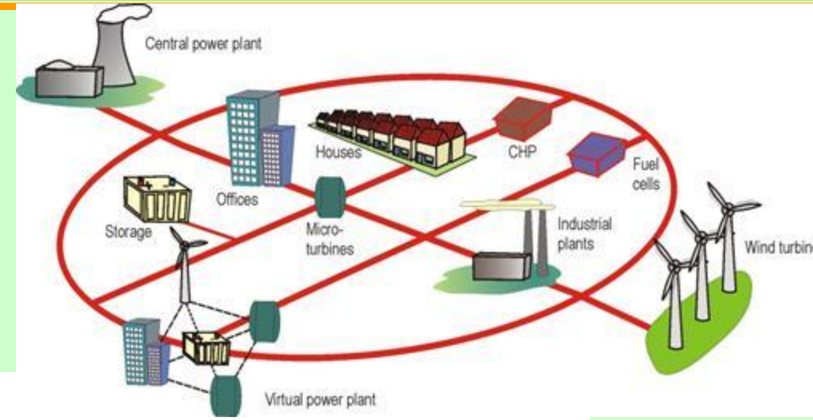
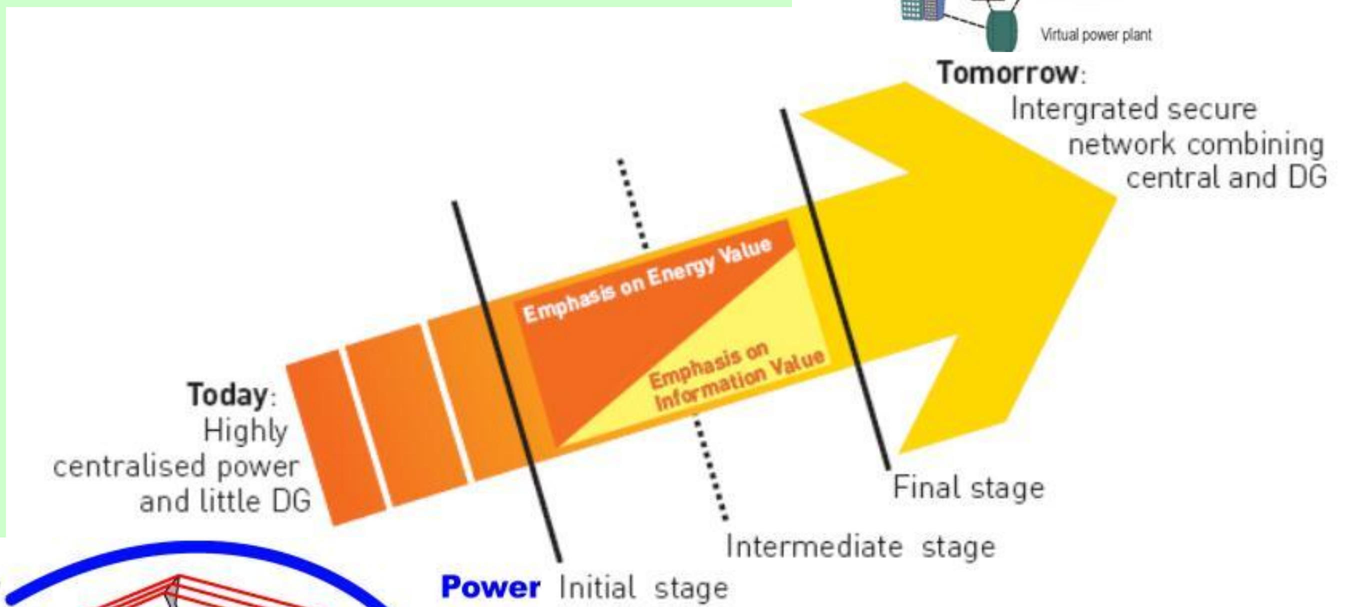
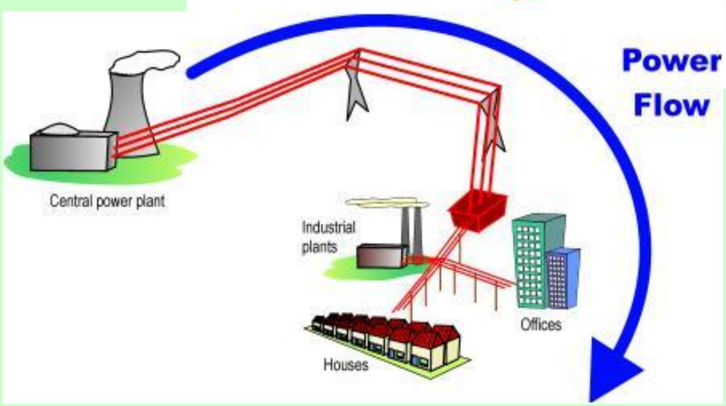
In transition



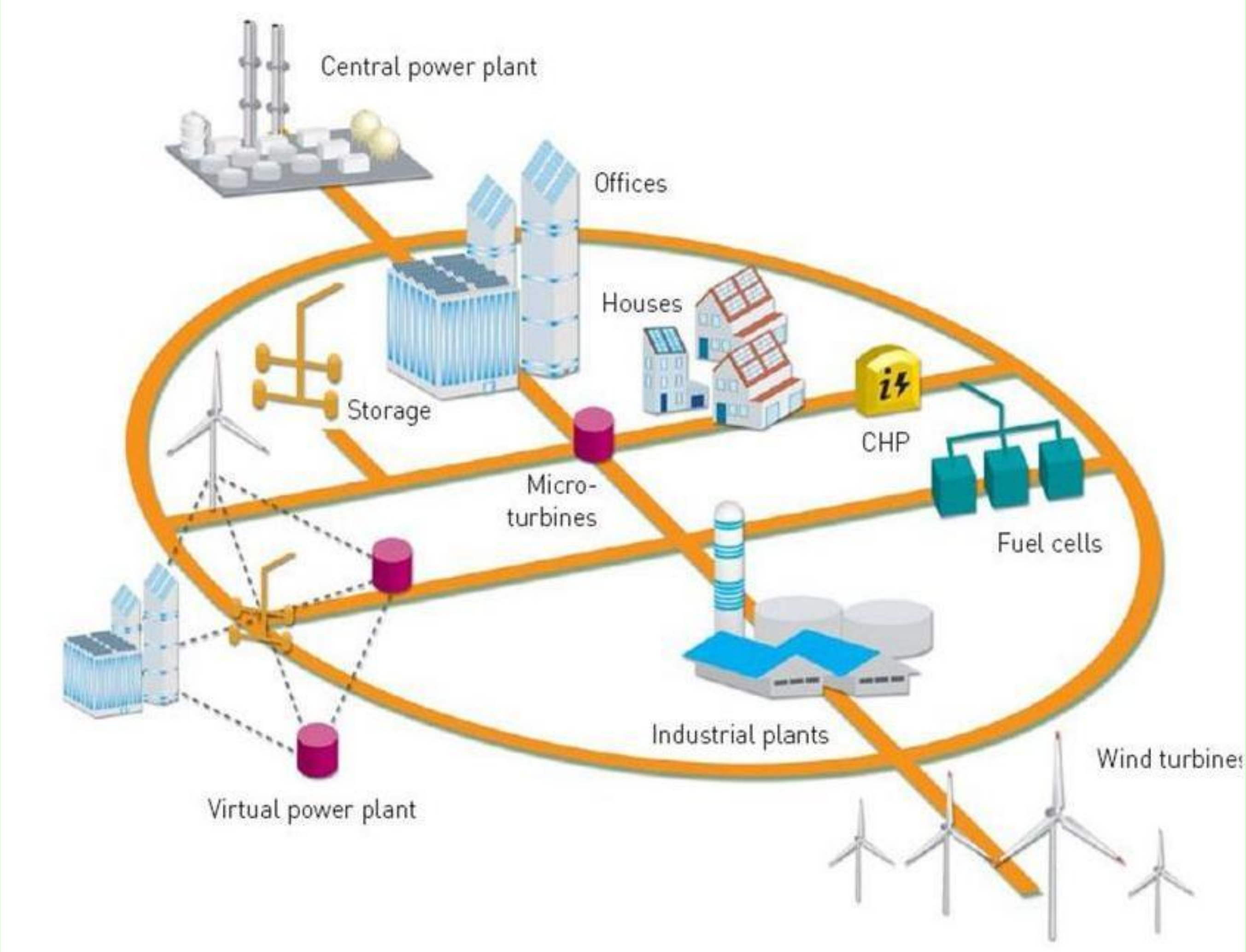




Transition: driving factors

- European and national policies encourage lower carbon generation, RES and efficient energy use
- Need for investment in end-of-life grid renewal (ageing assets)
- Handle grid congestion (with market based methods)
- Reduce uncertainty for investment
- Integration of RES and DG into the grids
- Increased customer participation
- Progress in technology

Networks tomorrow



DER with fully integrated network management

Future characteristics

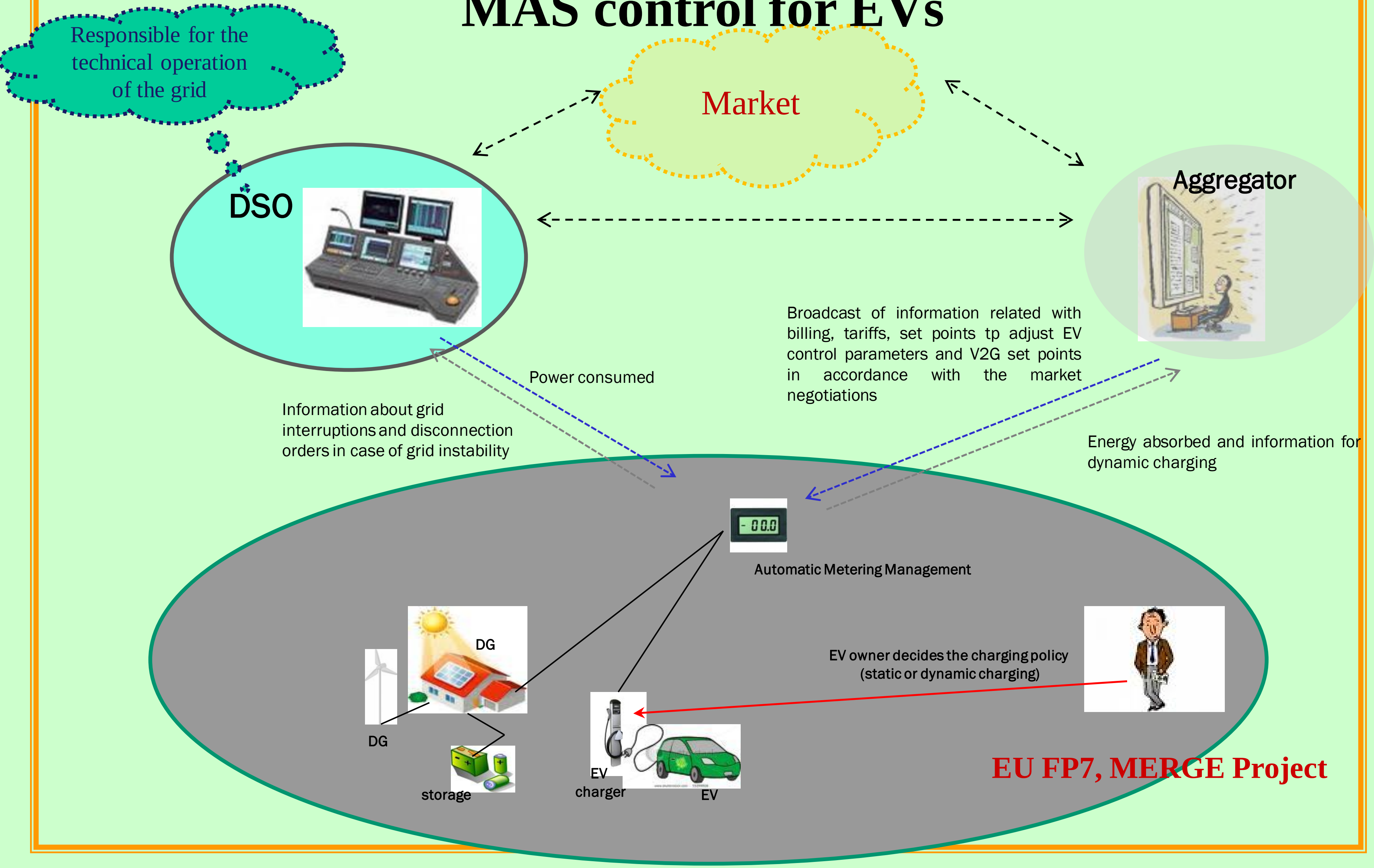
- Customers are part of the "network-loop", both producer and consumer = *"prosumer"*
  - Real-time price information (smart meters)
  - Automated systems + convenience (DR/DSM)
  - Adequate investment and reward incentives
- Integration of millions small scale generators
- Bulk power and small scale sustainability coexistence
- Demand and supply balance solutions
- Efficient operated (and reliable) network
- Differentiated Power Quality at connection point
- Mature markets and regulation

DER Technical, economic and environmental benefits

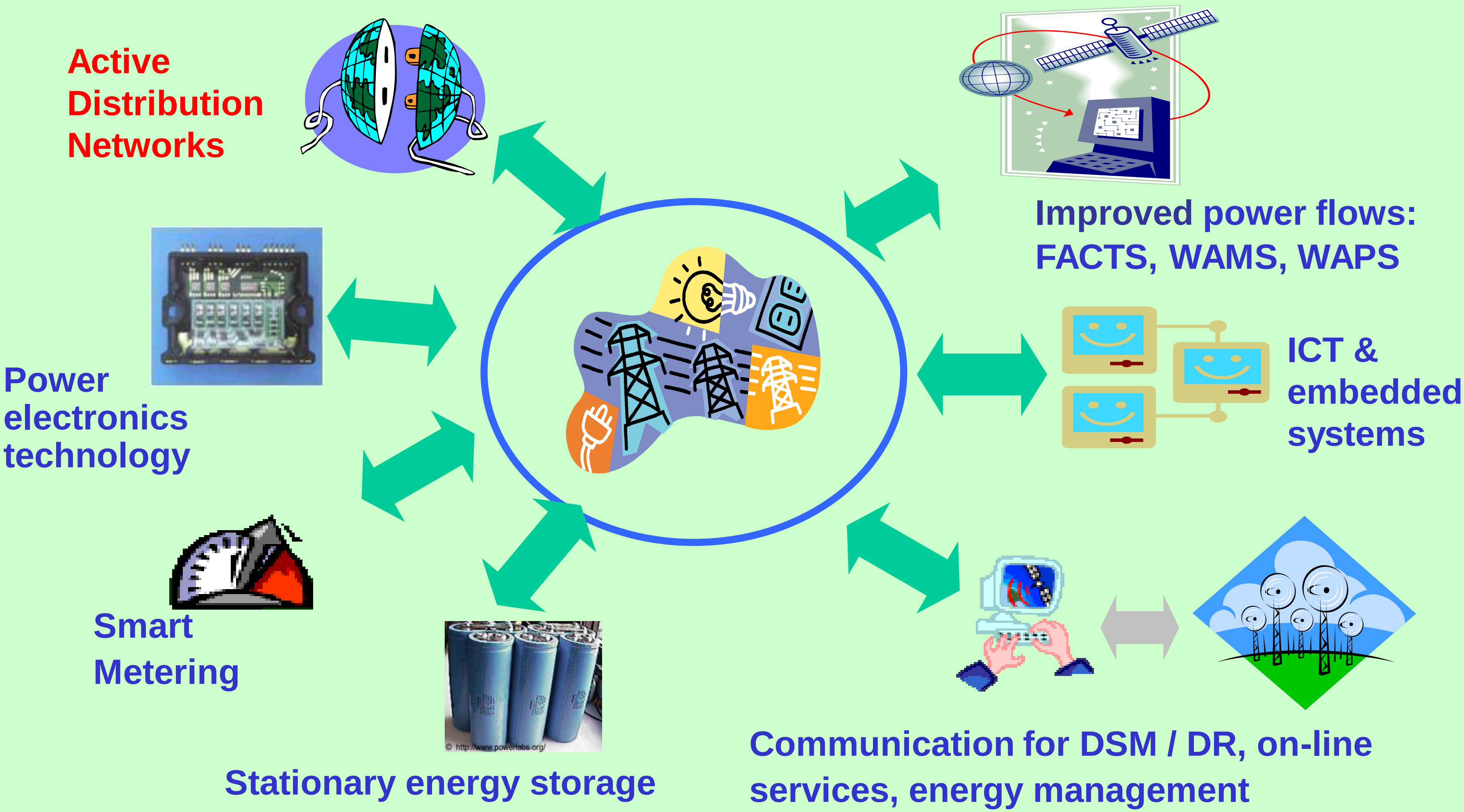
- Energy efficiency
- Minimisation of the overall energy consumption
- Improved environmental impact
- Improvement of energy system reliability and resilience
- Network benefits
- Cost efficient electricity infrastructure replacement strategies
- *Cost benefit assessment*

Electric Vehicles

MAS control for EVs



Enabling Technologies

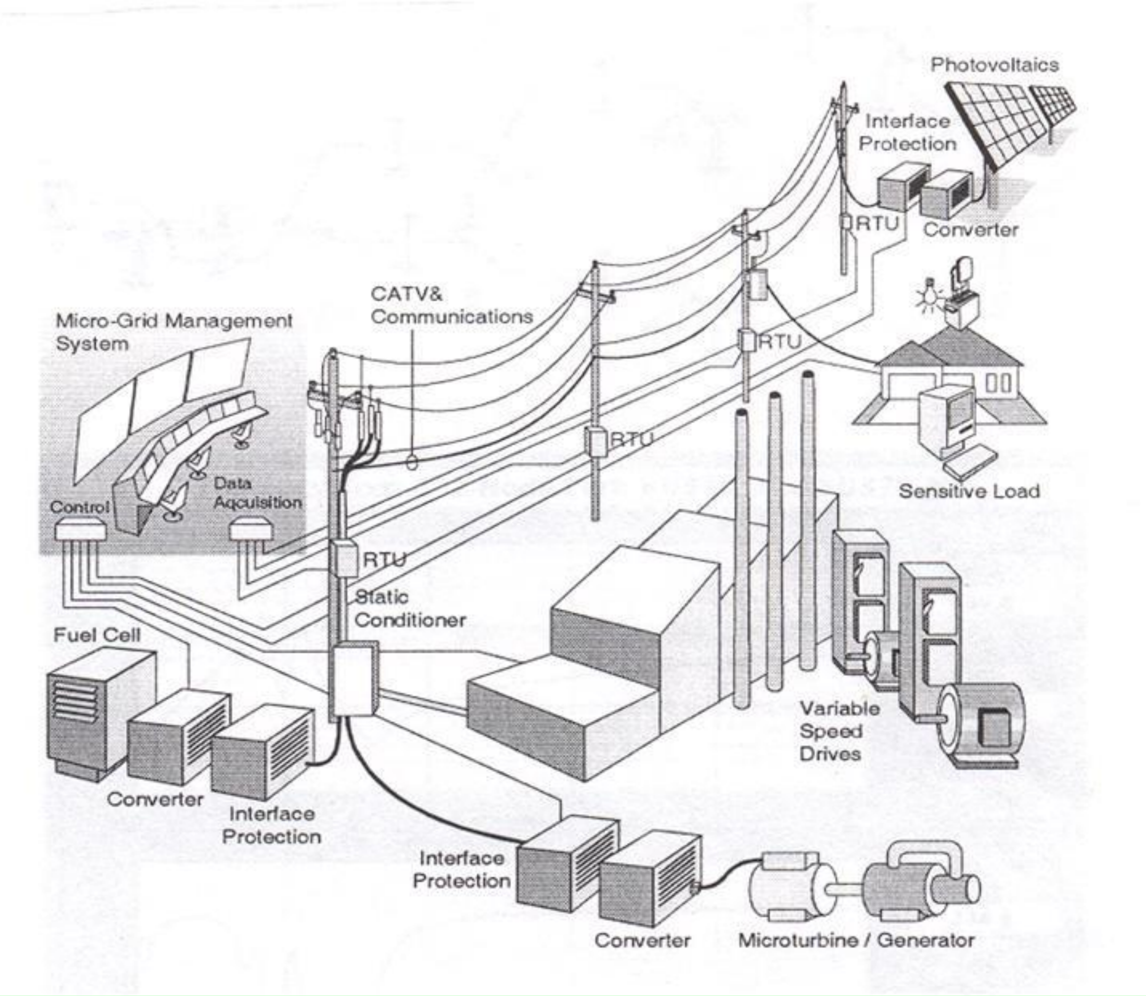


Microgrids

http://www.microgrids.eu

Interconnection of small, modular generation to low and medium voltage distribution systems can be organized in **Microgrids**.

Microgrids can be **connected** to the main power network **or operated islanded**, in a **coordinated, controlled** way.



EU Microgrids (ENK5-CT-2002-00610) and MOREMICROGRIDS (PL019864)

Control & Coordination: Is it necessary?

- The coordinated operation of several DGs and Loads (Consumers) increases the efficiency and provide opportunities for better network management.
- Consumers, DG owners and the network may have financial and operational benefits.
- These benefits derive from applying DSM policies, Congestion Management, Black Start, lower losses etc.

Technical Challenges for Microgrids

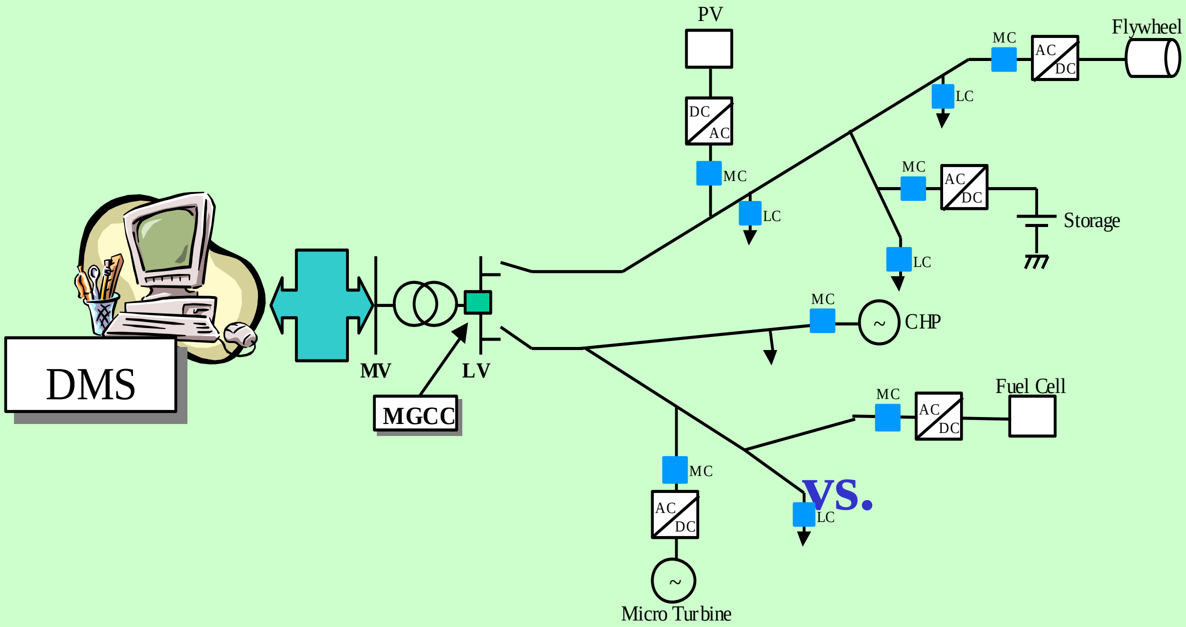
- Relatively large imbalances between load and generation to be managed (significant load participation required, need for new technologies, review of the boundaries of microgrids)
- Specific network characteristics (strong interaction between active and reactive power, control and market implications)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

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 – 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

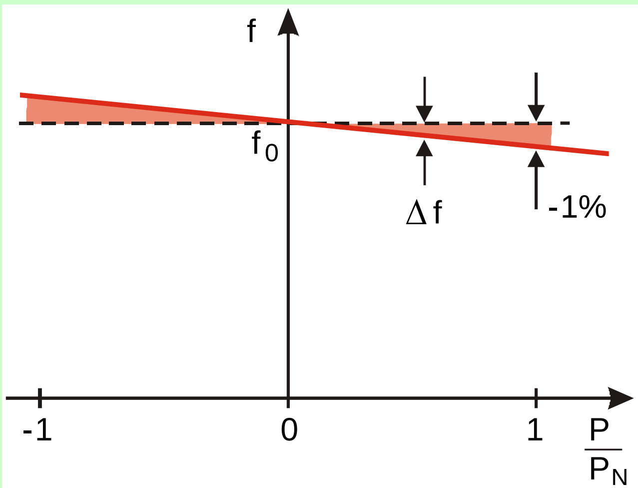


Centralized

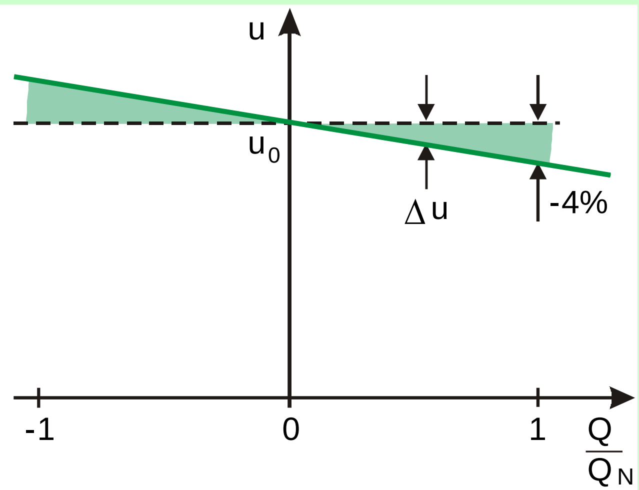
vs.

Decentralized Control

Parallel operation of inverters



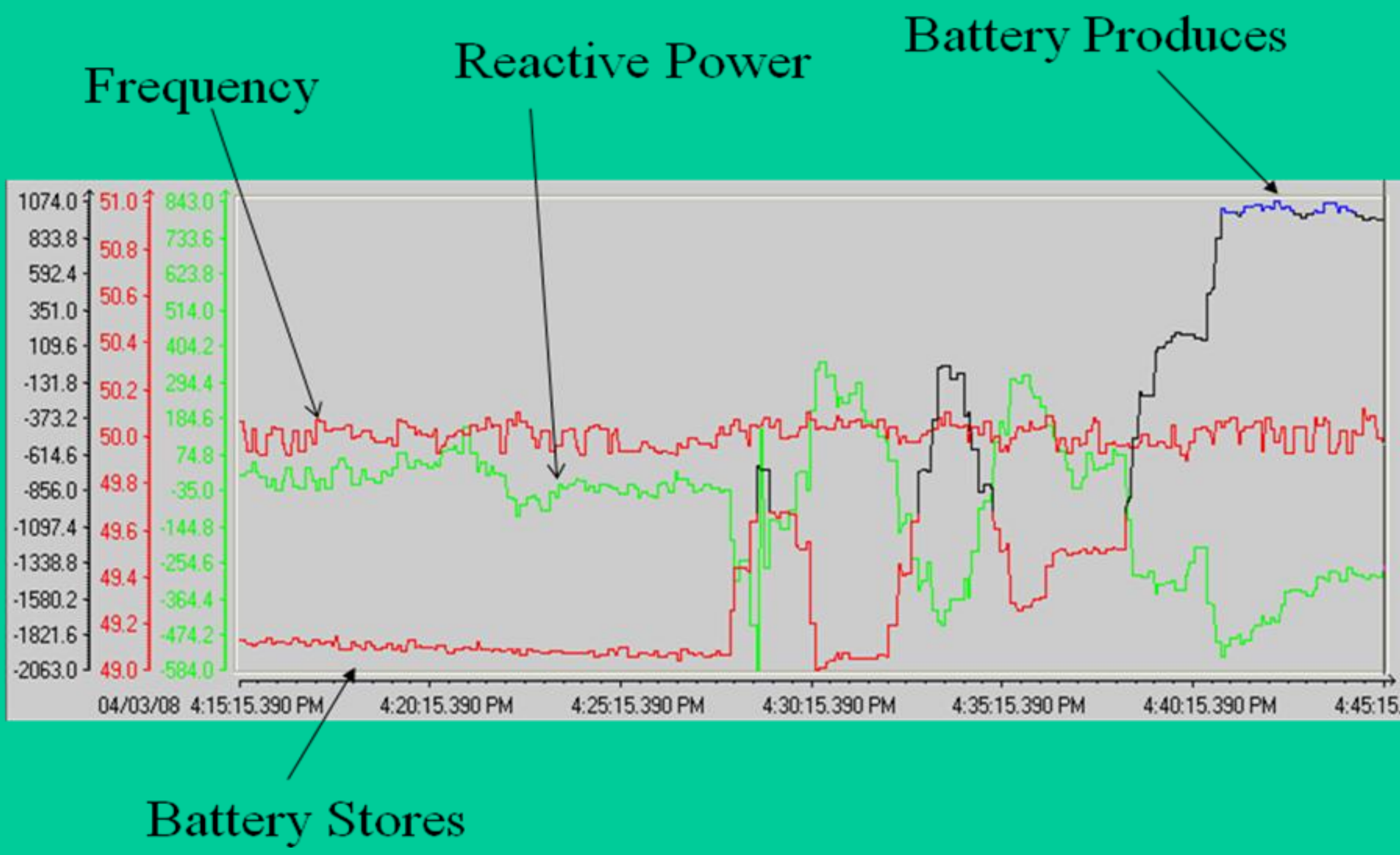
Frequency droop



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.

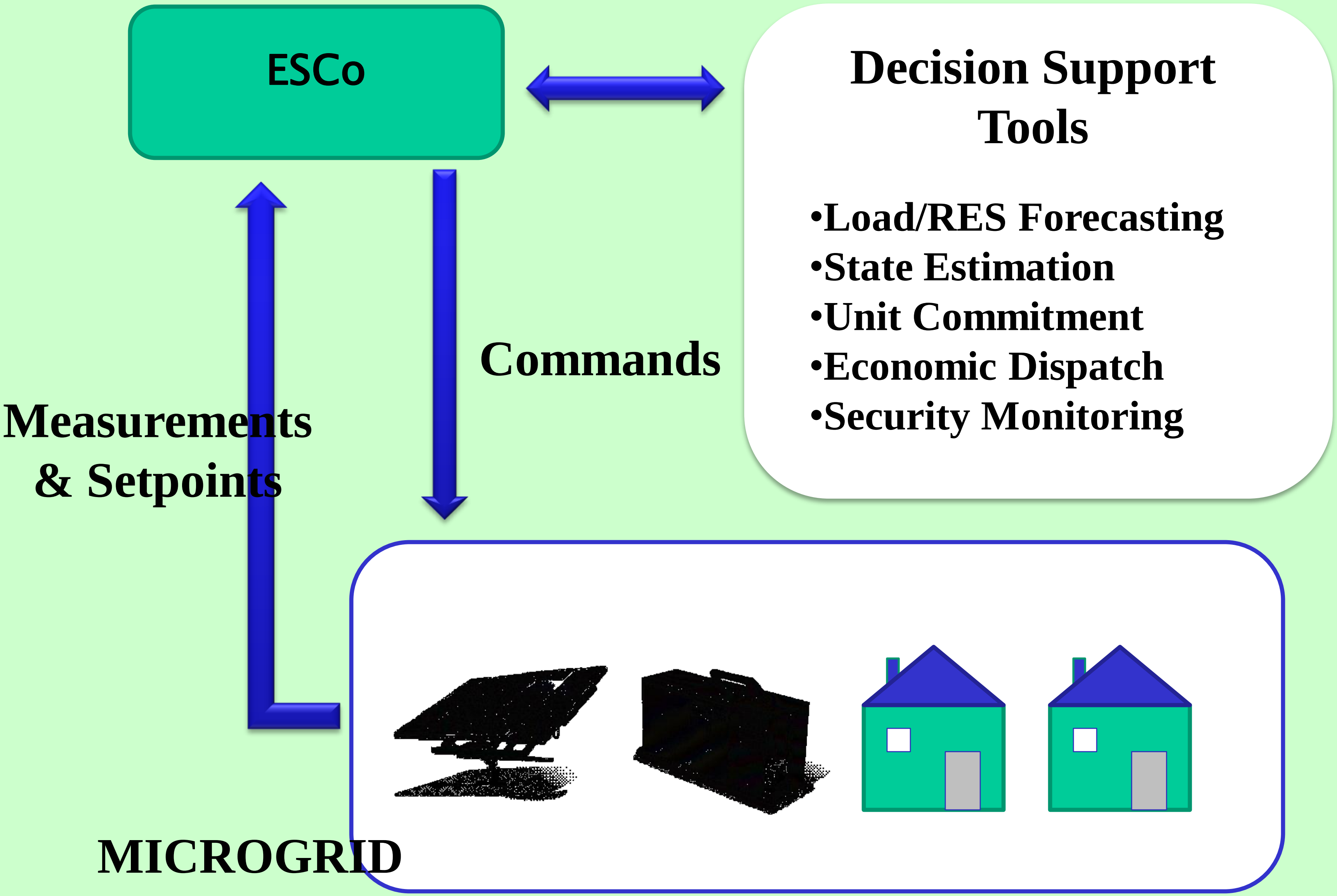
Control of Battery in the Laboratory



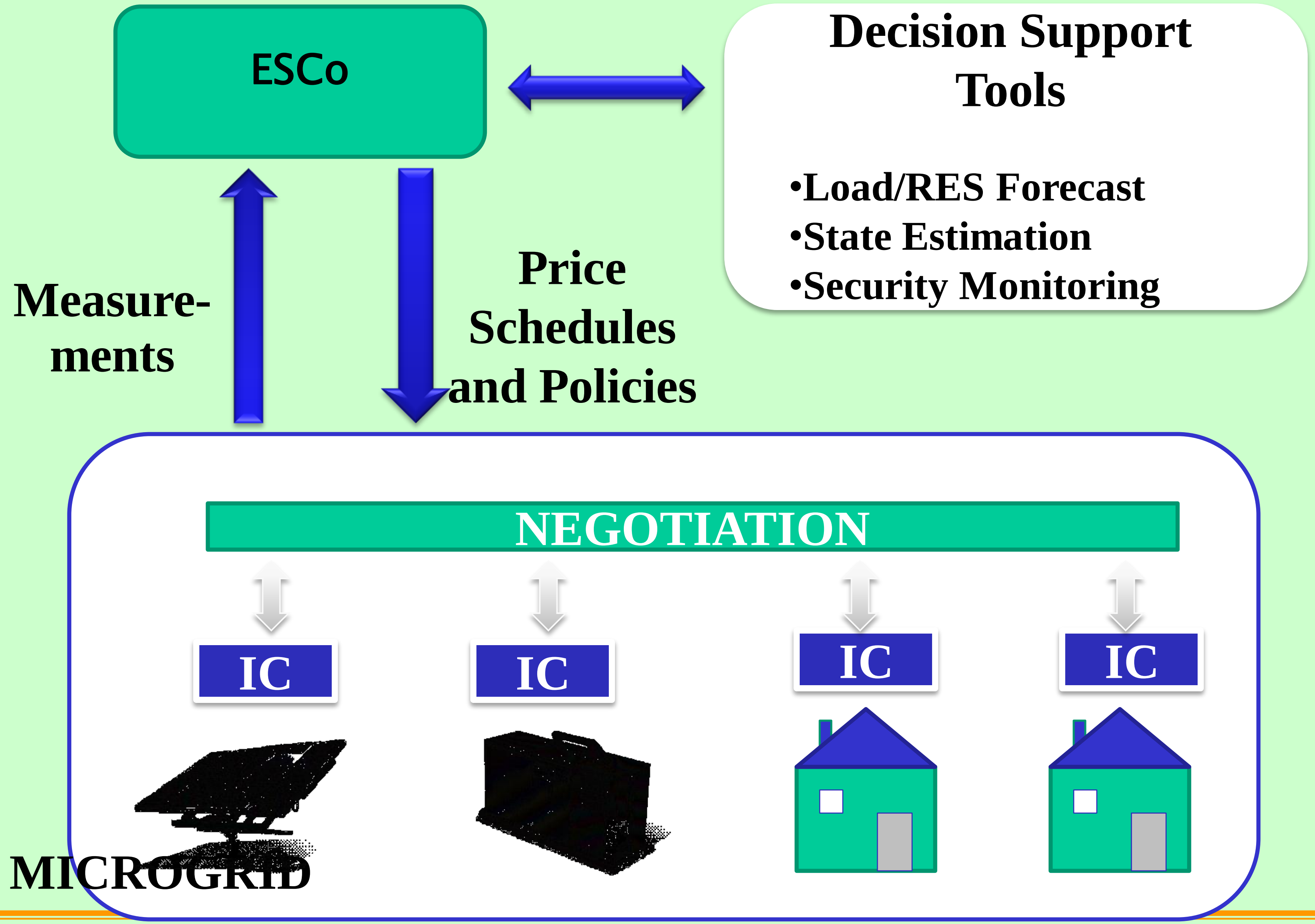
Centralized & Decentralized Control

- **The main distinction is where decisions are taken**
- **The Centralized Approach implies that a Central Processing Unit collects all the measurement and decides next actions.**
- **The Decentralized Approach implies that advanced controllers are installed in each node forming a distributed control system.**
- **Choice of approach depends on DG ownership, scale, ‘plug and play’, etc.**

The Centralized Approach



The Decentralized Approach



Implementing the Decentralized Control Concept

- **One approach of implementation adopts the intelligent agent approach**
- **Next, some basic concepts of the agent theory will be presented as well some practical examples.**

The Agent

- Physical entity that acts in the environment or a virtual one
- Partial representation of the environment
- Agents communicate – cooperate with each other
- Agents have a certain level of autonomy
- The agents have a behaviour and tends to satisfy objectives using its resources, skills and services

Reactive	Cognitive
partial representation of the environment	Memory
autonomy	Environment Perception
possesses skills	High level communication

Reactive vs Cognitive

Reactive

- The agent reacts to certain signals
- The collaboration of several reactive agents may form a intelligent society
- Typical example: the ant colony
- For an electrical network a protection device is a reactive agent.
- Several protection devices may create a self healing network

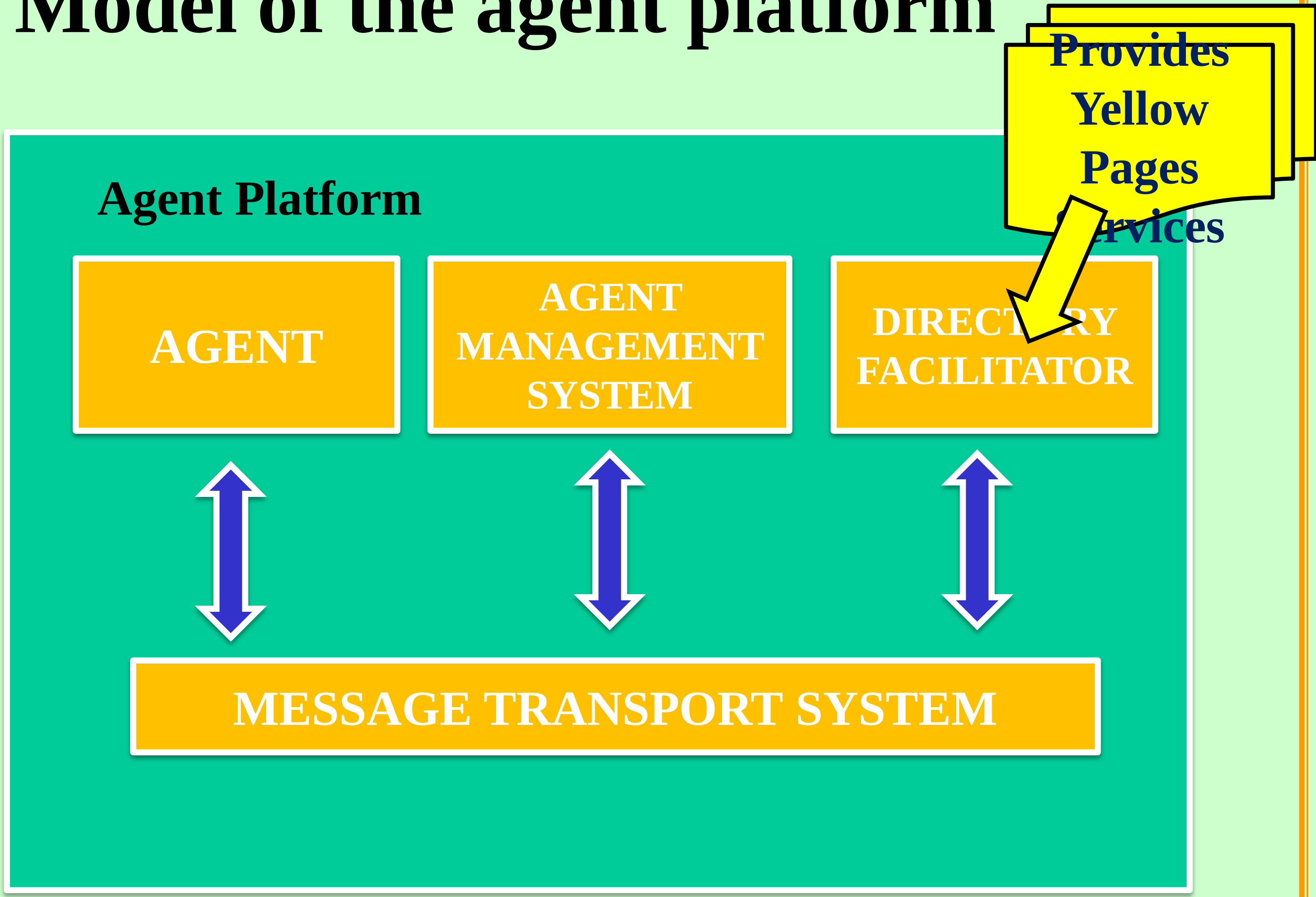
Cognitive

- The agent has increased intelligence and advanced communication capabilities.
- The collaboration is supported by the intelligence and the communication capabilities
- Typical example: the human society

Implementing Agent with Java-Jade

- Jade is a Java based platform for agent implementation.
- It is compatible with FIPA requirements
- FIPA is the Foundation for Intelligent Physical Agents
- Jade provides a set of libraries that allow the implementation of the agents.

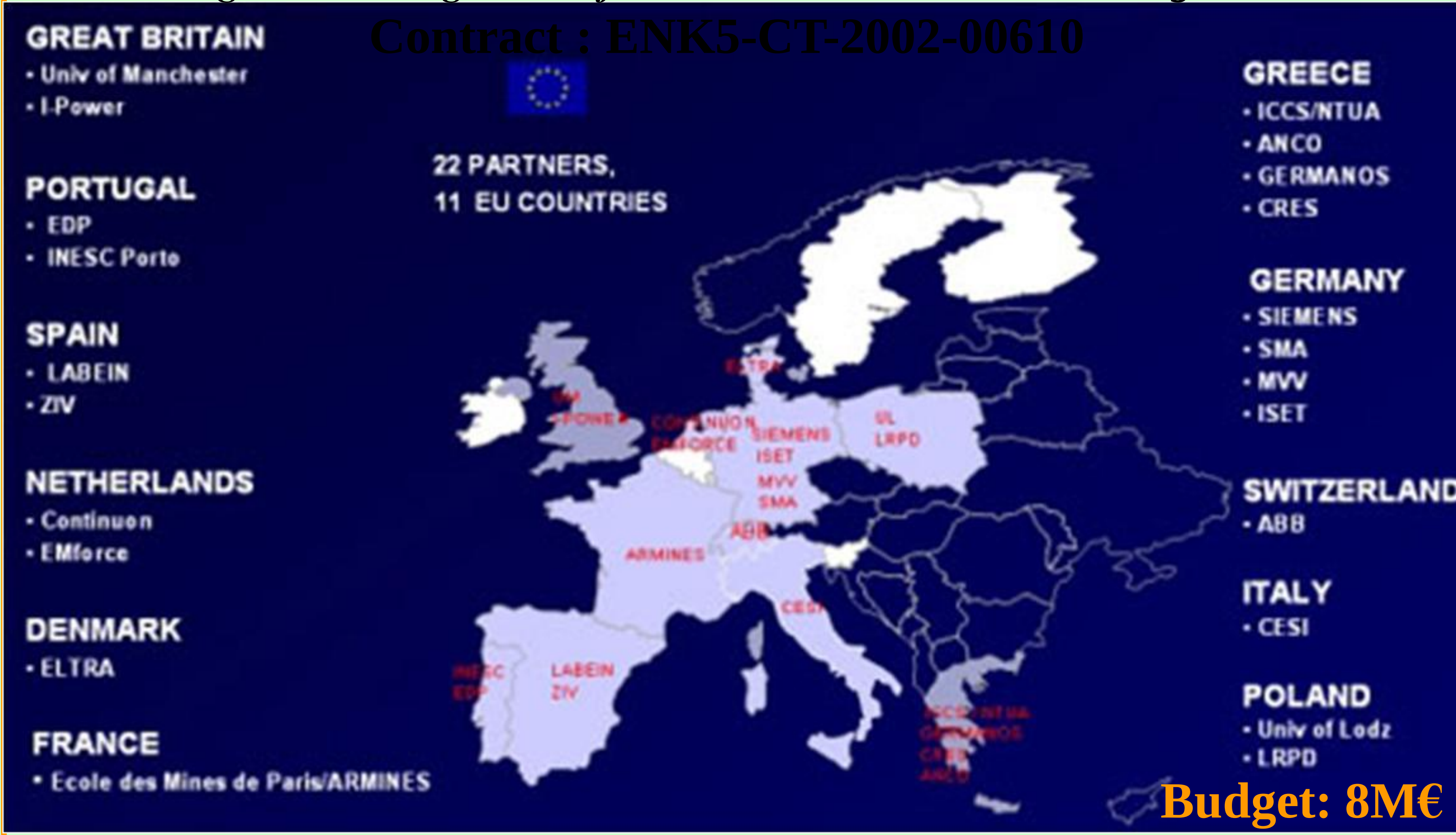
Model of the agent platform



MORE MICROGRIDS Project

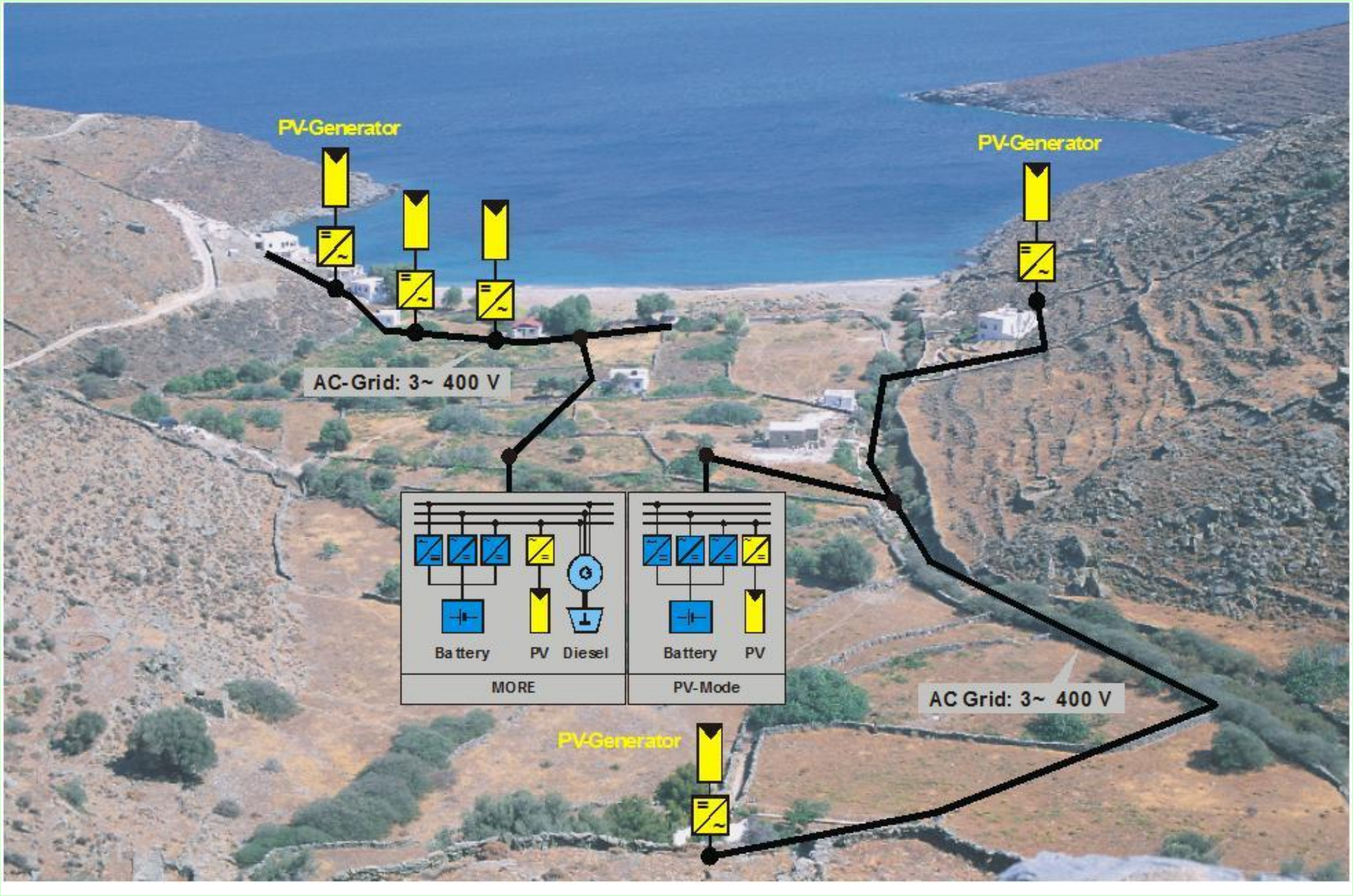
"Large Scale Integration of Micro-Generation to Low Voltage Grids

Contract : ENK5-CT-2002-00610



Budget: 8M€

Pilot Kythnos Plant



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

Typical House

Next generation Sunny Island inverters, to deal with islanded mode control

Intelligent Load Controllers

The test site is a small settlement of 12 houses

Generation:

5 PV units connected via standard grid-tied inverters.

A 9 kVA diesel genset (for back-up).

Storage: Battery (60 Volt, 52 kWh) through 3 bi-directional inverters operating in parallel.

Flexible Loads: 1-2 kW irrigation pumps in each house

The Kythnos System House

Goal of the Kythnos Experiment

- The goal of the experiment is to test the agent based control system in a real test site in order to increase energy efficiency.
- The main objective is to test the technical challenges of the MAS implementation.
- The technical implementation is based on intelligent load controllers and the Jade Platform
- The algorithm regarding the increase of the energy efficiency is quite simple and focuses in the limitation of the pump operation.

Goals of the Experiment

Software

- Java/Jade implementation
- CIM based ontology

Hardware

- Embedded Controller
- Measurements
- Communication
- Control via PLC

Technical

- Implement Distributed Control
- Test in real Environment

Electrical

- Increase energy efficiency
- Manage Non Critical Loads

The MAS System

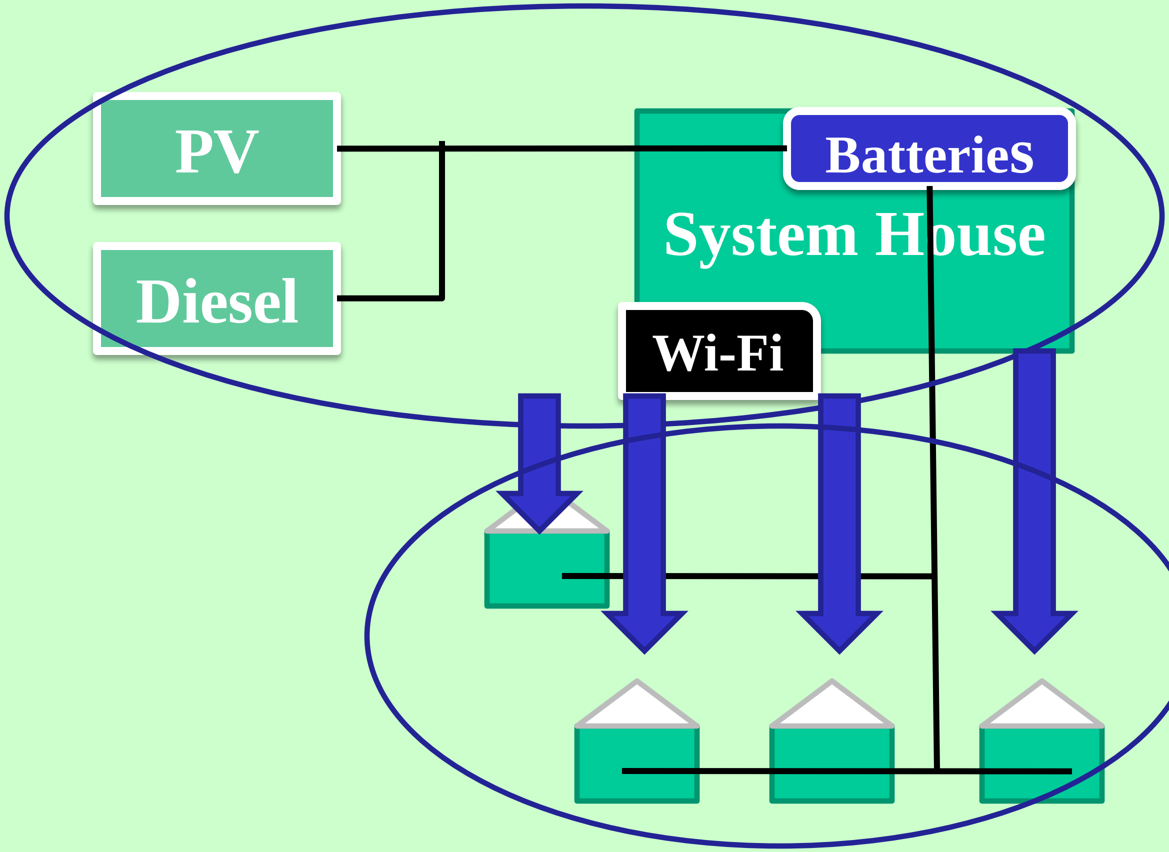
The MAS tries to increase the energy efficiency. The steps are the following:

1. The system decides the available energy that can be used by the pumps.
2. The houses decide how to share this energy.

The Process of the experiment

Step 1: The agents identify the status of the environment

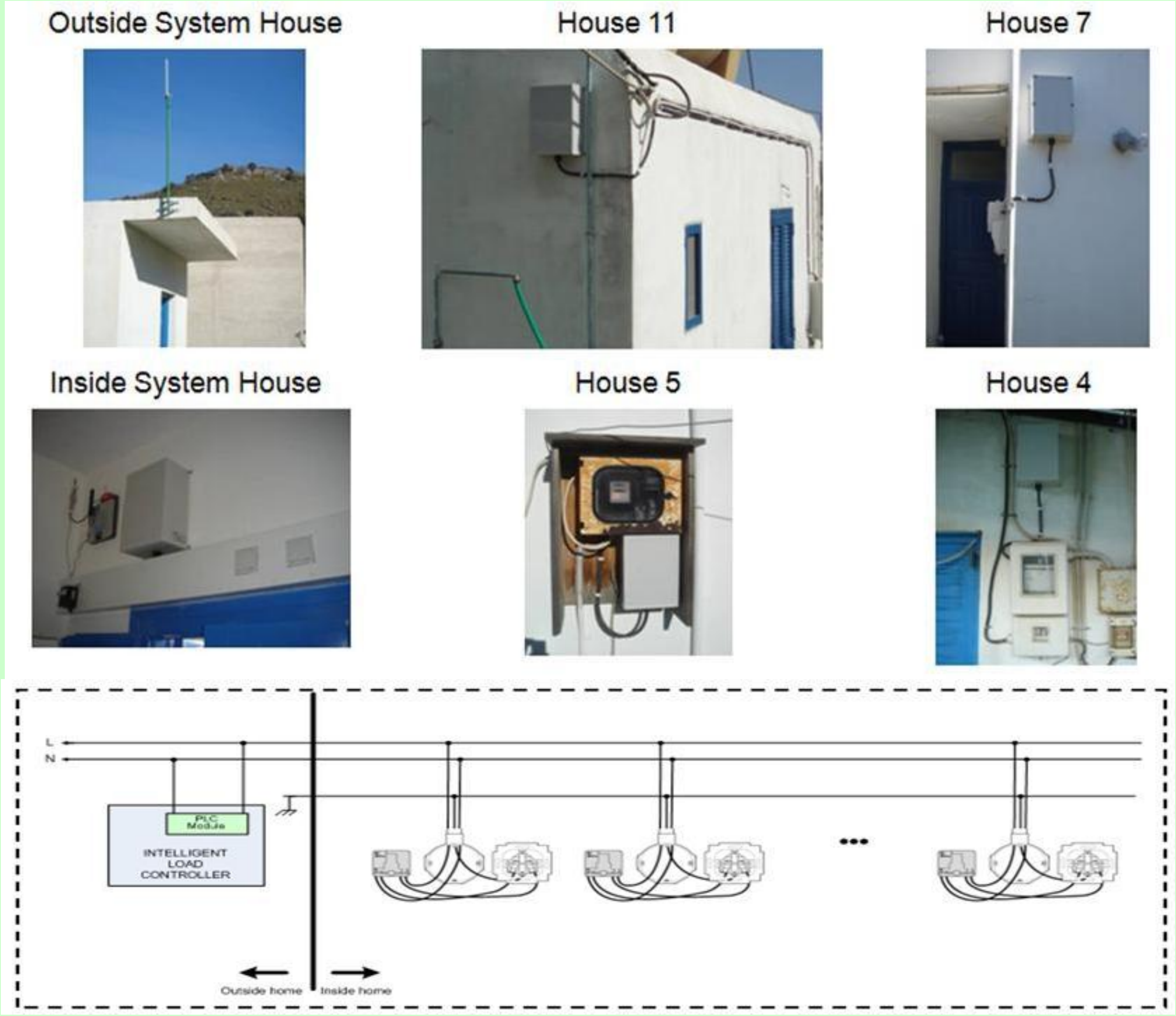
Step 2: The agents negotiate on how the share the available energy



Intelligent Load Controllers

In each house an ILC is installed:

- **Windows CE 5.0**
- **Intel® XscaleTM PXA255**
- **64MB of RAM**
- **32MB FLASH Memory**
- **Java VM**
- **Jade LEAP**



Auction Algorithm

- One significant part of the agent communication and decision process is the auction algorithms.
- The auction algorithm is a tool that allows the agents to decide which one of them will acquire a certain object or a good.

English Auction

- In the English Auction the auctioneer seeks to find the market price of a good by initially proposing a price below that of the supposed market value and then gradually raising the price.
- Each time the price is announced, the auctioneer waits to see if any buyers will signal their willingness to pay the proposed price. As soon as one buyer indicates that it will accept the price, the auctioneer issues a new call for bids with an incremented price.
- The auction continues until no buyers are prepared to pay the proposed price, at which point the auction ends. If the last price that was accepted by a buyer exceeds the auctioneer's (privately known) reservation price, the good is sold to that buyer for the agreed price. If the last accepted price is less than the reservation price, the good is not sold

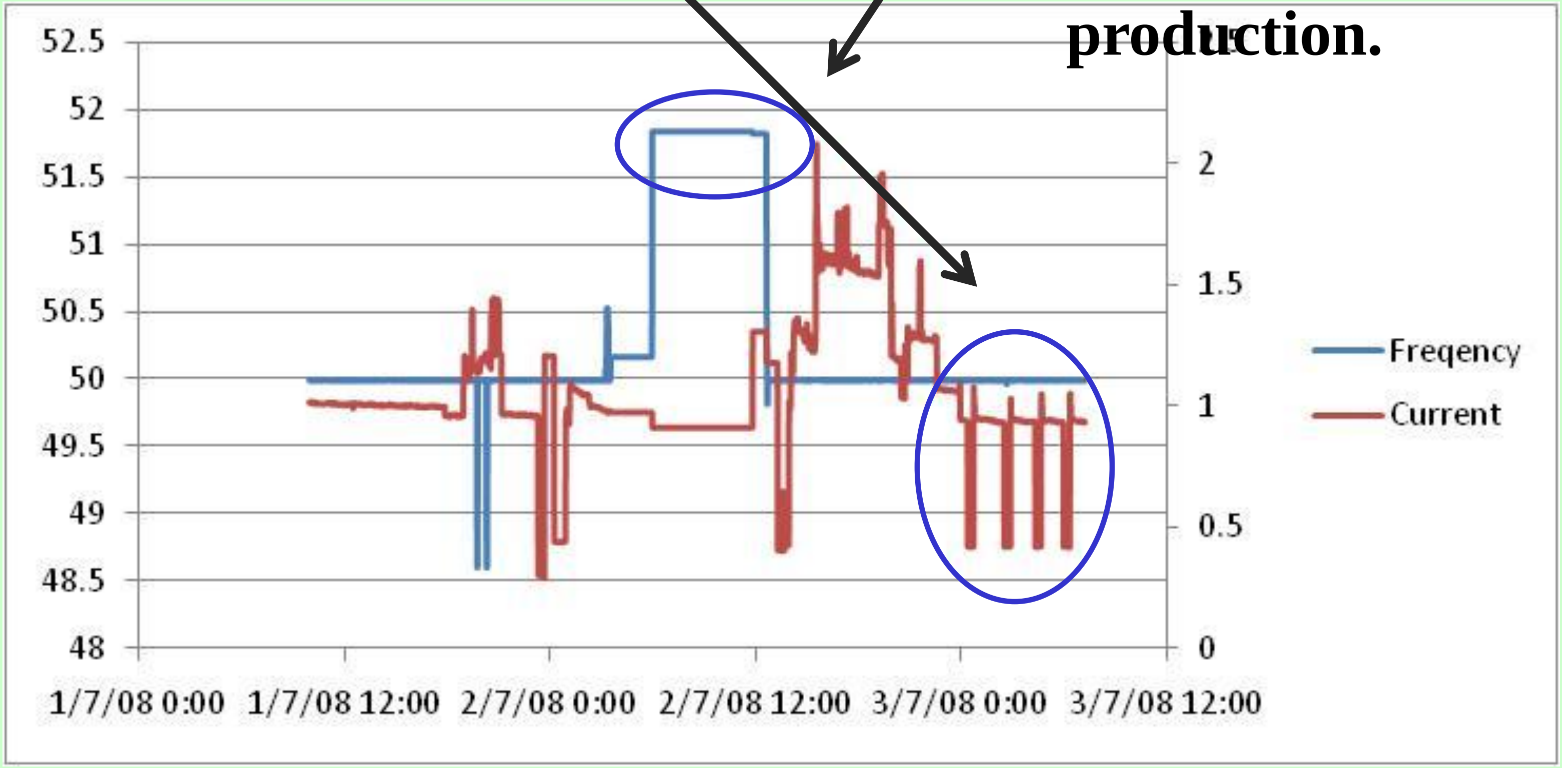
Example: Policies to estimate the available energy

- SOC of the Battery: This is an indication of the available energy of the system. The amount of energy above a certain level can be used (example >90%)
- The system frequency. If the system frequency is above 50Hz this is an indication that the batteries are full and part of the PV production is rejected

Measurements

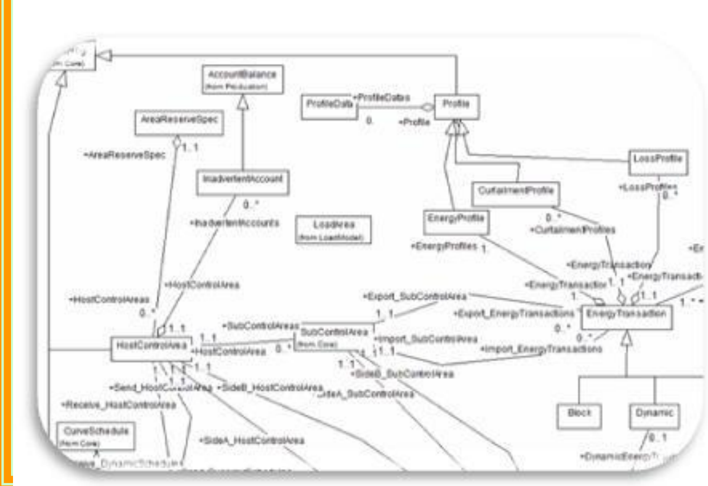
In this case the frequency if almost 52Hz. This is an indication that the batteries are full and the PV inverters via the droop curves limit their production.

The shedding procedures start later

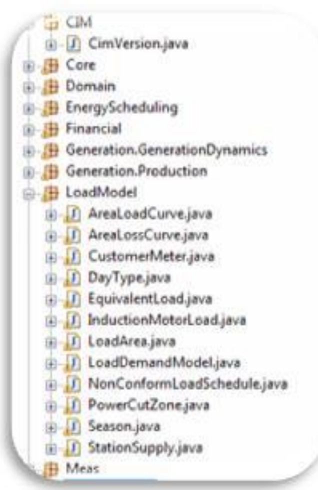


Communication

- The main goal of this installation was to test a real MAS.
- One critical part of any implementation MAS implementation is the ontology.
- In Kythnos test site a CIM (IEC 61970) based ontology was tested.



The UML based description of the power system has been transformed to Java Classes and used as an ontology



It works !!!

Conclusions

- The Kythnos was the first test site where the MAS system was implemented
- A Controller with an Embedded processor has been used to host the agents.
- New techniques have been tested such as: negotiation algorithms, wireless communication, CIM based ontology etc..
- The architecture is too complex for small systems but offers great scalability.

MAIN CONCLUSION:

Intelligent Decentralized Control key for the effective coordination of the multitude of distributed generators and active loads.

Thank you!