Centralized and Decentralized Microgrid Control

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Microgrids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way, either while connected to the main power network and/or while islanded.

(CIGRE WG C6.22)

http://www.microgrids.eu
Three essential Microgrid features: local load, local micro-sources, and intelligent control. Different than DG interconnection or Demand Side Integration.

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Typical Microgrids Misconceptions

• Microgrids are exclusively isolated (island) systems.
• Customers who own micro-sources build a Microgrid.
• Microgrids composed of intermittent RES must be unreliable and easily subject to failures and total black-outs.
• Microgrids are expensive to build, so the concept will be limited to field tests or only to remote locations.
• Microgrid controllers will force consumers to shift their demand depending on the availability of renewable generation, i.e. Sun shining or wind blowing.
• A Microgrid is such a totally new idea, that system operators need to rebuild their entire network.
• Microgrids loads will never face any supply interruptions.

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A virtual power plant (VPP) is a cluster of DER which is collectively operated by a central control entity. A VPP can replace a conventional power plant while providing higher efficiency and more flexibility.

Distinct differences:

• Locality
• Size
• Consumer Focus
Who will develop a Microgrid?
Who will own or operate it?

- Investments in a Microgrid can be done in multiple phases by different interest groups: DSO, energy supplier, end consumer, IPP (individual power producer), etc.
- The operation of the Microgrid will be mainly determined by the ownership and roles of the various stakeholders. Three general models:
  - DSO owns and operates the distribution grid and also fulfils the retailer function of selling electricity to end consumers. (DSO Monopoly)
  - ESCO are the actors that maximize the value of the aggregated DG participation in local liberalized energy markets (Liberalized Market)
  - Consumer(s) own and operate DG to minimize electricity bills or maximize revenues (Prosumer Consortium)
Identification of Microgrid benefits is a multi-objective and multi-party coordination task

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Technical Challenges

• Small size (challenging management)
• Use of different generation technologies (prime movers)
• Presence of power electronic interfaces
• 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)
• Protection and Safety / static switch
• Communication requirements

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Market 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

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Centralized & Decentralized Control

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

Microgrid serving its own needs using its local production, when financially beneficial.

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

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

- 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 DG
- The technical constraints for interconnection and the DG

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CIGRE Benchmark: LV network with multiple feeders

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Study Case
LV Feeder with DG

CIGRE Benchmark

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Simulation Tool of Market Participation

emissions avoided during the last 6 hours

CO2: 37 kgr
SO2: 184 gr
NOx: 155 gr
Particles: 49 gr
Residential Feeder with DGs

Prosumer Consortium: Cost Reduction 12.29 %
27% reduction in CO₂ emissions

Liberalized Market: Cost reduction 18.66%

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Demand Side Bidding

Two Demand Side Bidding options

- Consumers bid for supply of high and low priority loads. The total demand is found by the aggregation of DSBs and DG bids – Option A

- Consumers offer to shed low and high priority loads at fixed prices according to their bids and paid for this service. The total demand is assumed known beforehand – Option B
DSB Results – Single day

- Total energy shed 232 kWh (7.27%)
- Total cost reduction 34.79% for option A
- Cost reduction 31.44% for option B
- Reducing average prices for the Microgrid consumers

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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

![Diagram of Microgrid System](image)
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 tend to satisfy objectives using its resources, skills and services

Reactive

Cognitive or Intelligent

Memory

Environment Perception

High level communication

Partial representation of the environment

Autonomy

Possesses skills

Typical example: an ant colony

Typical example: the human society

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Agent Communication

A significant characteristic of agents. The Agent Communication Language allows the interaction and the knowledge sharing.

One significant part of the agent communication is the auction algorithm

According to the fundamental principles of economic theory, fair bidding leads to optimal solutions

The auction algorithm is an important tool for agent applications.

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Behaviour, objectives, resources, skills and services

**Behavior**
- Competitive
- Collaboration

**Objectives**
- Maximize profit
- Minimize cost

**Resources**
- Available Fuel
- Energy Stored in a Battery

**Skills**
- Load Curtailment
- Black Start

**Services**
- Yellow pages
- Data Storage

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Agents Implementation 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 agent platform

Agent Platform

AGENT

AGENT MANAGEMENT SYSTEM

DIRECTORY FACILITATOR

MESSAGE TRANSPORT SYSTEM

Provides Yellow Pages Services

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The implementation of the system requires a network of computers capable to host Java Applications and communicate over TCP/IP (internet protocols).
MICROGRIDS Project (FP5)

“Large Scale Integration of Micro-Generation to Low Voltage Grids”, PROJECT N°: NNE5-2001-00463

14 PARTNERS, 7 EU COUNTRIES

GREAT BRITAIN
- UMIST
- URENCO

PORTUGAL
- EDP
- INESC

SPAIN
- LABEIN

NETHERLANDS
- EMforce

Greece
- NTUA
- PPC/NAMD&RESD
- GERMANOS

Germany
- SMA
- ISET

France
- EDF
- Ecole des Mines de Paris/ARMINES
- CENERG

Budget: 4.5M€

http://www.microgrids.eu

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MORE MICROGRIDS
“Advanced Architectures and Control Concepts for more Microgrids”, Contract: SES6-PL019864

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Microgrids Pilots

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Supply of 12 buildings (EC projects MORE, PV-Mode, More Microgrids)

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Advanced Sunny Island inverters, to deal with islanded mode control

Intelligent Load Controllers

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

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The Kythnos System House

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Goals of 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.

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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 to share the available energy

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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

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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.
• In this experiment the simple algorithm called English Auctions is implemented
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.
The shedding procedures start later

In this case the frequency is almost 52Hz. This is an indication that the batteries are full and the PV inverters via the droop curves limit their production.
One critical part of any implementation MAS implementation is the ontology. In Kythnos 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.
Highlights

Control
- Implementation of Distributed Control
- The houses decide their actions

Software
- Java Based Application
- FIPA Compliant Architecture
- CIM Based ontology

Hardware
- Embedded Controller
- Communication & Control Capabilities

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Technical 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.

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Non-technical lessons learned

• MAS for energy optimization provides a technical limitation and protection of the system to prevent over-use. This helps to maintain the good relationships between the neighbours.

• Importance of involving or at least explaining to users negotiation process to equally share the available energy - development of demonstration software

• The technical and economical aspects of system operation are evaluated positively: the system works quite reliably, users pay regularly, the maintenance and repairs of the system are well organized.

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It works !!!
Purely Decentralized Techniques - Gossip Protocols

• The fundamental concept behind gossip algorithms is that every participating node interacts with one or more nodes and exchanges a piece of information.

• Information is anticipated to be disseminated rapidly like a virus (another name for gossip protocols is epidemic algorithms).

• Appealing characteristics: fault-tolerant & scalable.

• Fully capable of distributed calculation of separable functions

\[ F = \sum_{i=1}^{n} f_i(P_1, ..., P_n) \]
Gossip Protocols (2)

- A common gossip algorithm framework consists of 3 steps:
  - selection of neighboring nodes for information exchange
  - determination of available information to be exchanged
  - information processing
- Every participating node conducts periodically these 3 steps

### Active thread

**do once** for each T time units at a random time

begin
  
  $p = \text{SelectPeer}()$
  
  **send** DataExchange ($state$) to $p$
  
  **receive** $info_p$ from $p$
  
  $state = \text{DataProcesing}(info_p)$

end

### Passive thread

**do forever**

begin

  **receive** $info_p$ from $p$

  **send** DataExchange ($state$) to $q$

  $state = \text{DataProcesing}(info_q)$

end

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Gossip Protocols (3)

• The selection criterion for neighboring nodes can be stochastic, following normal distribution, predetermined based on distance metrics or taking into account connection “preferences” (connection weights)

• The determination of information to be exchanged divides gossip algorithms into the following categories: push, pull or concurrently push & pull for faster convergence

• The appropriate processing of information creates the desirable results: e.g. SUM, AVERAGE, MIN, MAX

EXAMPLE OF DISTRIBUTED AVERAGE CALCULATION

```plaintext
// vector w is the input
do N times
  (i, j) = GETPAIR()
  // perform elementary variance reduction step
  w_i = w_j = (w_i + w_j)/2
return w
```
Practical Applications

• Power grid state estimation by distributed calculation of electric quantities

• Distributed optimization of grid operation (congestion management, losses reduction, voltage deviations) gaining access only to locally available information

• The wide deployment of smart meters with enhanced capabilities (bidirectional communication, information storage and processing) creates the infrastructure for such applications

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Further Reading…

http://www.smartrue.gr

Thank you!


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