Centre for Energy and Environmental Markets

UNSW

Overview of Microgrid Management and Control

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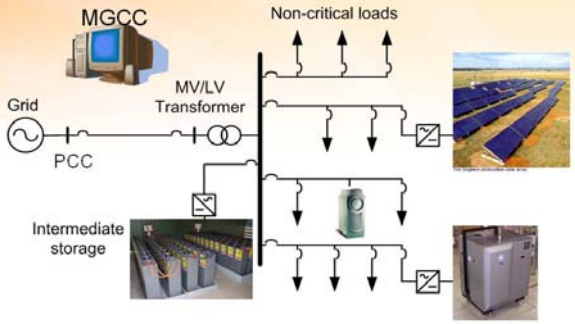
Outline

- Introduction
- Microgrids Research
- Management of Microgrids
- Agent-based Control of Power Systems

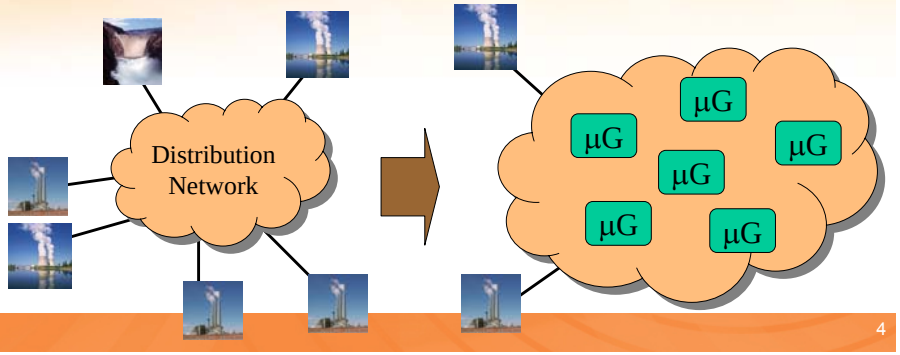
Introduction

- What is a microgrid?



Introduction

- Objectives
  - Facilitate penetration of distributed generators to the distribution network
  - Provide high quality and reliable energy supply to critical loads



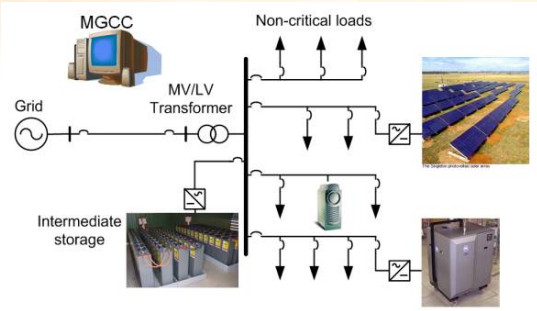
Introduction

- Microgrid components
  - Distributed generation (microsources)



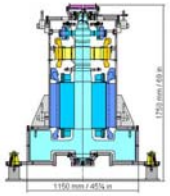
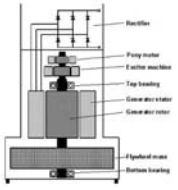

Introduction

- Microgrid components
  - Distributed generation (microsources)
  - Loads



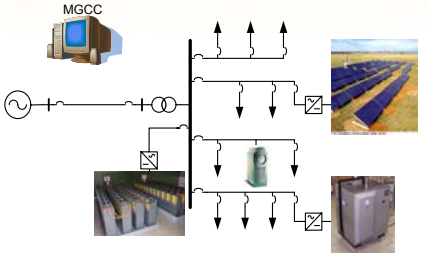
Introduction

- Microgrid components
  - Distributed generation (microsources)
  - Loads
  - Intermediate storage

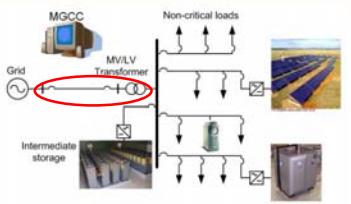
Introduction

- Microgrid components
  - Distributed generation (microsources)
  - Loads
  - Intermediate storage
  - Controller
    - Centralized; hierarchical
    - Decentralized; distributed



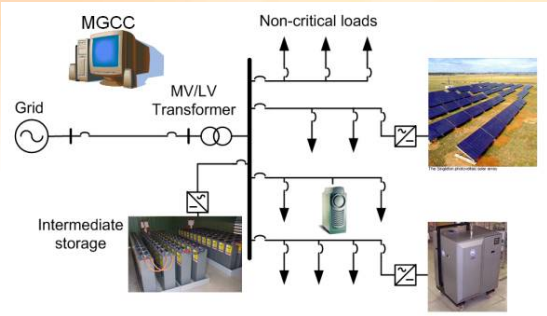
Introduction

- Microgrid components
  - Distributed generation (microsources)
  - Loads
  - Intermediate storage
  - Controller
  - Point of common coupling



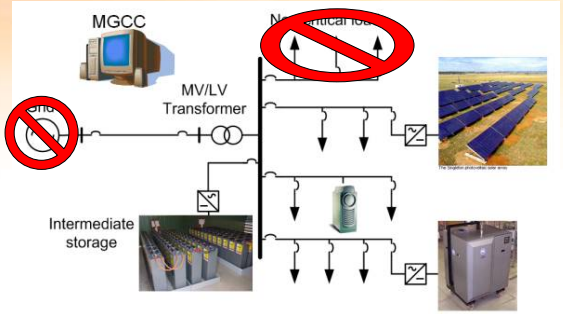
Introduction

- Grid-connected operation



Introduction

- Island operation



Introduction

- Research highlights[1]
  - Control philosophies
  - Energy management
  - Microsource and load issues
  - Analysis tools

[1] DER and Microgrids: Research Topics within the EU Framework Programs. Presented by Nikos Hatziargyriou (NTUA) at the Berkeley Symposium on Microgrids, June 2005

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Microgrid Research

EU, USA, Japan and Canada

The Microgrids Project (EU)

- 2002-2005
- The Consortium:

http://microgrids.power.ece.ntua.gr/micro/micro2000/index.php?page=index

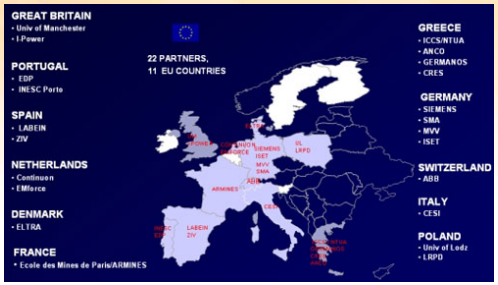
Successful Results[1]

- "Investigation, development and validation of the operation, control, protection, safety and telecommunication infrastructure of Microgrids"
- "Validate the operation and control concepts in both stand-alone and interconnected mode on laboratory Microgrids"

[1]*Overview of Microgrid research and development activities in the EU,* Manuel Sanchez, Montreal 2006 – Symposium on Microgrids

More Microgrids

- 2006 – 2010
- 8.5 M€ budget
- Consortium



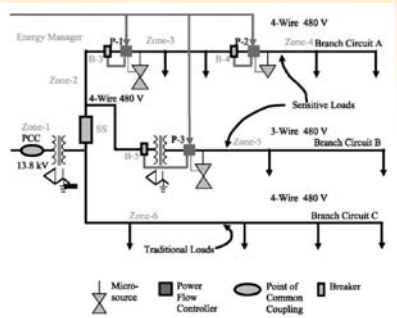
http://microgrids.power.ece.ntua.gr/micro/index.php?page=index

More Microgrids

- Advanced control techniques for local Distributed Resources and load controllers
- Integration of several Microgrids into operation. Interaction with DMS.
- Standardization and benchmarking.
- Field trials to test control strategies on actual Microgrids
- Impact assessment of Microgrids on power system operation and planning
- Cooperation and learning from alternative, complementary approaches, under development in US, Canada and Japan

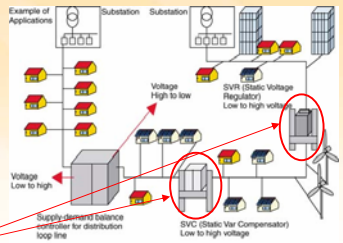
US Microgrid Research

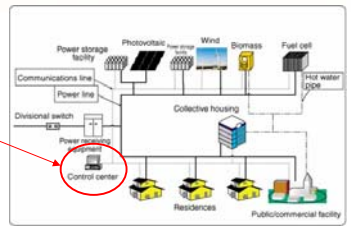
- Consortium for Electric Reliability Technology Solutions (CERTS)
- Power Systems Engineering Research Center (PSERC)
  - The CERTS Microgrid Concept (2002)
  - Autonomous Control of Microsources (2006)
  - CERTS Microgrid Testbed (2006)
- LBNL: DER-CAM



Japan Microgrid Research

- The New Energy and Industrial Technology Development Organization (NEDO)
  - Demonstrative Project on New Power Systems (2004-2007)
  - Demonstrative Project of Regional Power Grids with Various New Energies (2003-2007)





Images from the NEDO website:
http://www.nedo.go.jp/english/activities/2_sinenergy/3/p04020e.html and
http://www.nedo.go.jp/english/activities/2_sinenergy/3/p03038e.html

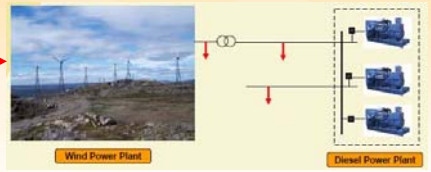
Canada Microgrid Research[1]

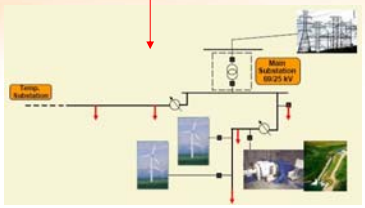
- CANMET Energy Technology Center – Varrenes
  - DER Integration Standards and Codes
    - MicroPower Connect
  - Net Metering
  - Impact of Large Scale DER Integration
    - Microgrid case studies

[1]http://ctec-varennes.rncan.gc.ca/en/er_re/inter_red.html

Canada Microgrid Research

- Microgrid Case Studies
  - Remote microgrid
  - Utility microgrid





  - Intentional island network

Management and Control of Microgrids

Technical Challenges[1]

- Management of imbalance between load and generation
- Specific network characteristics
- Loss of aggregation
- Microsource issues
- Protection and safety

[1] *DER and Microgrids: Research Topics within the EU Framework Programs. Presented by Nikos Hatziargyriou (NTUA) at the Berkeley Symposium on Microgrids, June 2005*

Market and Regulatory Challenges[1]

- Decentralized energy trading
- Need for market mechanisms that will ensure secure supply of energy
- Development of islanded and grid-connected price-based energy and ancillary services agreements
- Secure and open access to network and allocation of network costs
- Ownership structures
- New responsibilities of generation and distribution companies and consumers

[1] DER and Microgrids: Research Topics within the EU Framework Programs. Presented by Nikos Hatziargyriou (NTUA) at the Berkeley Symposium on Microgrids, June 2005

Management and Control Approaches

- CERTS: Autonomous Control
- The Microgrids Project: Centralized and Distributed Control
- C. Rehtanz: MicroGrid Agent
- G. Celli etal: NN-based EMS

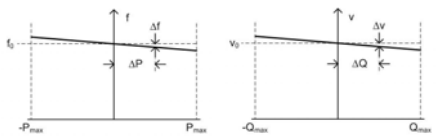
CERTS/UW-M for CEC-DOE

- Autonomous Control of Microsources[1]
  - Emphasis on peer-to-peer and plug-and-play operation model
    - Eliminate single point of failure
    - Install one additional microsource
  - Control of microsource generation
    - Unit power control
    - Feeder flow control
    - Mixed control configuration

CERTS
Consortium for Electric Reliability Technology Solutions

CERTS/UW-M

- Unit Power Control
  - Microsource outputs constant real power
  - Q-v droop controls the reactive power output
  - P-f droops control the real power output when the microgrid islands



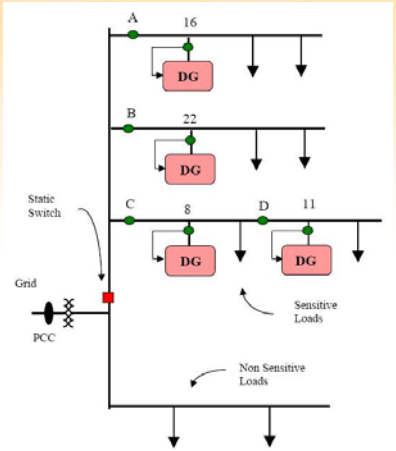


Image from "Control and Design of Microgrid Components," P. Piagi and R. Lasseter, Final Project Report, PSERC, January 2006

CERTS/UW-M

- Feeder flow control
  - Microsource regulates the real power flowing through the feeder
  - Q-v droop controls the reactive power output
  - P-f droops control the real power output when the microgrid islands
- Mixed control configuration

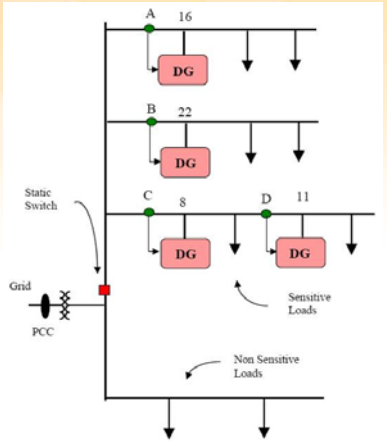


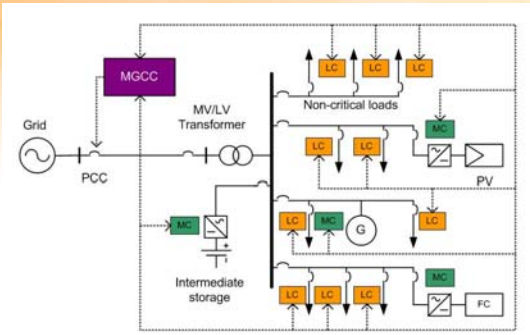
Image from "Control and Design of Microgrid Components," P. Piagi and R. Lasseter, Final Project Report, PSERC, January 2006

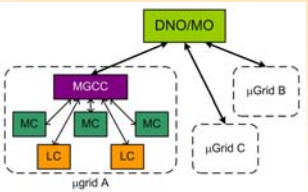
The Microgrids Project

- Hierarchical control
  - Use of a central controller (MGCC)
  - MGCC optimizes microgrid operation
- Fully decentralized control
  - Use of multi-agent technology
  - Microsources have different owners and perform specific tasks

Hierarchical Control

Control architecture:





DNO – Distribution Network Operator

MO – Market Operator

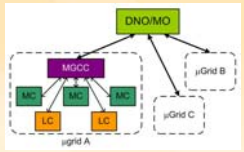
MGCC – Microgrid Central Controller

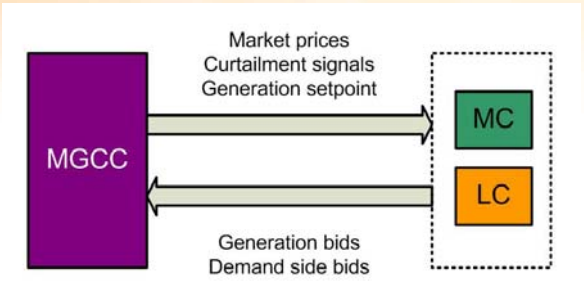
MC – Microsource Controller

LC – Load Controller

Hierarchical Control

- MGCC Organization





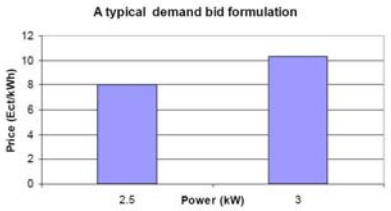
Hierarchical Control

Market Policies

- "Good Citizen" Behavior
  - Satisfy own energy demand
  - Does not export power
  - Reduction of network congestion
- "Ideal Citizen" Behavior
  - Participates in the energy market

Hierarchical Control

- Demand Side Bidding
  - Consumer participation to microgrid management
  - Option A: Consumer offers to *purchase* at different prices
  - Option B: Consumer offers to *shed loads* at different prices



Hierarchical Control

- Solution Methods
  - Use unit commitment and economic dispatch functions
  - "Good Citizen Behavior"
    - UC and ED – priority list method
  - "Ideal Citizen Behavior"
    - UC – priority list method
    - ED – sequential quadratic programming
  - Ant-colony optimization

Hierarchical Control

- Forecasting Functions
  - Electricity and heat demand
  - RES production
  - Electricity prices
- Security Assessment Functions

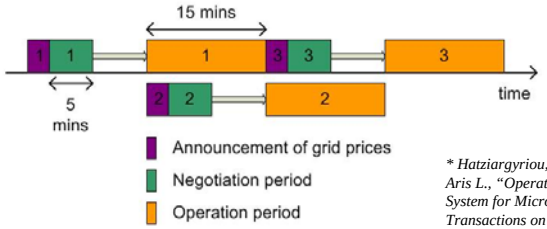
Decentralized Control

- Agent-based distributed control
  - Hatziargyriou & Dimeas, "Operation of a Multi-agent System for Microgrid Control"
  - J. Oyarzabal, J. Jimeno, J. Ruela, A. Engler and C. Hardt, "Agent based Micro Grid Management System"

Decentralized Control 1*

Hatziargyriou & Dimeas

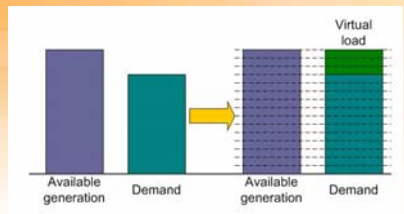
- Agents:
  - MGCC
  - Production unit agents (PU)
  - Load unit agents (LU)
  - Power seller market agent (SMA)
  - Power buyer market agent (BMA)

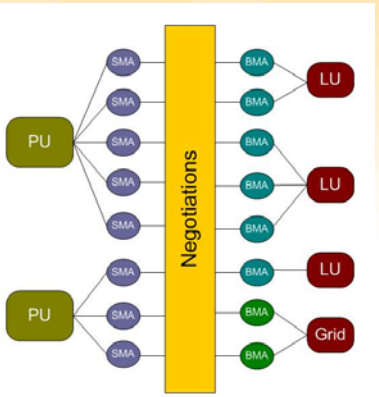


** Hatziargyriou, Nikos D. and Dimeas, Aris L., "Operation of a Multiagent System for Microgrid Control", IEEE Transactions on Power Systems, August 2005*

Decentralized Control 1

Hatziargyriou & Dimeas





Pairing of Seller and Buyer Market Agents is treated as a symmetrical assignment problem.

Decentralized Control 1

Hatziargyriou & Dimeas

- Symmetrical assignment problem
  - Match N pairs of persons and objects while maximizing the total benefit
  - b_{ij} = benefit of assigning buyer i to object j
    = value of object j to buyer i – cost of object j
  - Maximize $\sum_{i=1}^{N} b_{ij}$
  - Implementation
    - Loads announce demands and prices
    - Producers submit bids to loads
    - Loads accept or reject bids
    - Auction resolves conflict
    - Process repeats until all buyers are assigned to sellers

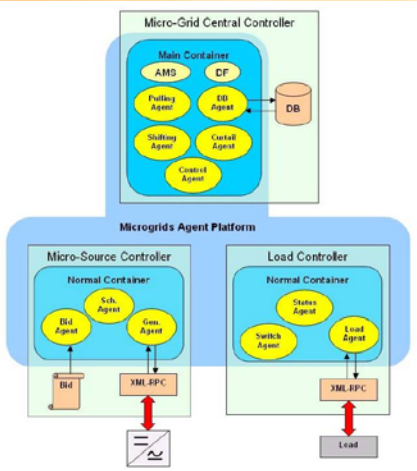
Decentralized Control 1

Hatziargyriou & Dimeas

- Implemented using Java Agent Development Framework (JADE)
- Number of agent pairs is limited by the maximum number of iterations (e.g. 105 iterations → 15 agent pairs)
- @ 250 Wh per market agent block → 3.75 kWh

Decentralized Control 2*

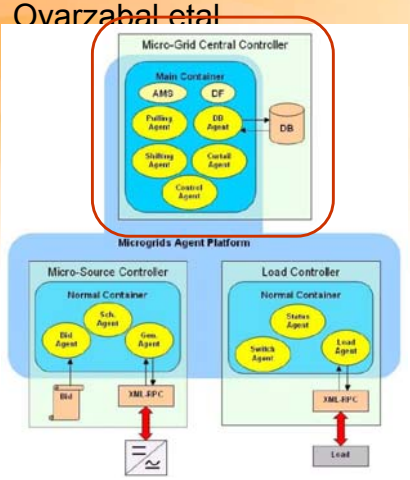
Oyarzabal etal



** Oyarzabal, J. etal, "Agent based Micro Grid Management System," 2005 International Conference on Future Power Systems, 16-18 November 2005*

Decentralized Control 2

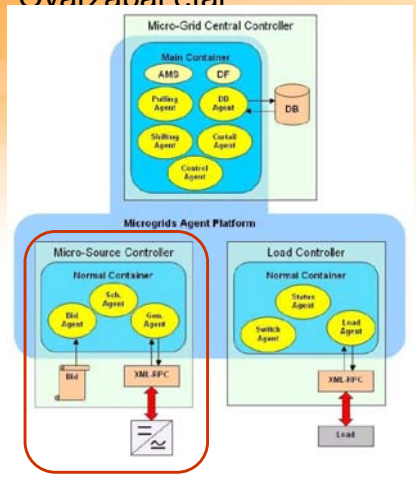
Oyarzabal etal



- MGCC (Main Container)
  - PA – collect source measurements and sells bids
  - DBA – database interface
  - CoA – secondary regulation
  - SA – load shifting actions
  - CuA – load curtailment actions

Decentralized Control 2

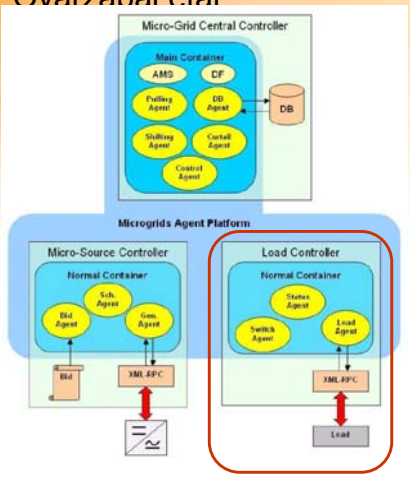
Oyarzabal etal



- Microsource Controller (normal container)
  - GA – generator interface
  - SchA – output power tracking
  - BA – sends selling bids

Decentralized Control 2

Oyarzabal etal

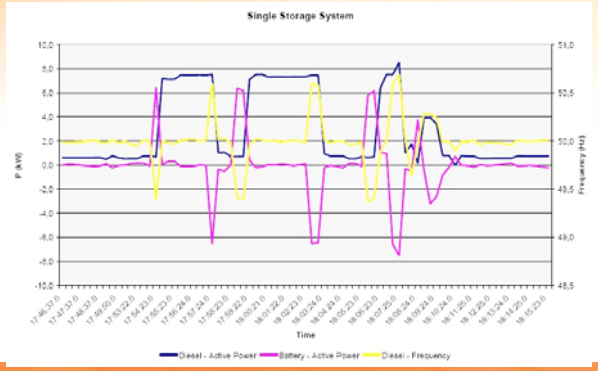


- Load Controller (normal container)
  - LA – sends shiftable and curtailable loads to MGCC
  - StA – on/off status of load
  - SwA – receives and executes shifting and curtailment actions

Decentralized Control 2

Oyarzabal etal

- Secondary control actions run every 30 secs
- Sample result:



Decentralized Control 2

Oyarzabal etal

- Scalability:
  - CNET Protocol
  - Intra-platform communication (HTTP)
    - 10 ms/dialog, linear increase in negotiation time for up to 7000 agents
  - Inter-platform communication (SUN ORB, ORBACUS, HTTP)
    - Degradation occurs after 3500 agents

MicroGrid Agent (MGA)

- Autonomous Systems and Intelligent Agents in Power System Control and Operation, Christian Rehtanz, © Springer-Verlag Berlin Heidelberg 2003
- MGA is adapted from Strategic Power Infrastructure Defense System
- Subsumption architecture

MicroGrid Agent (MGA)

- Subsumption layers: reactive, coordination and deliberative layer

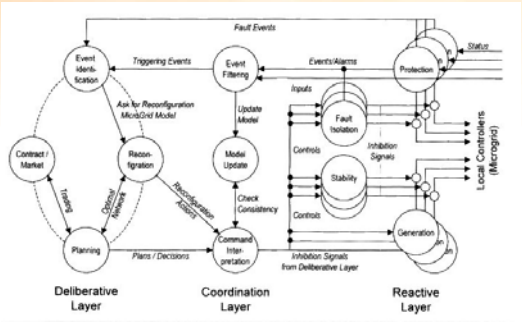
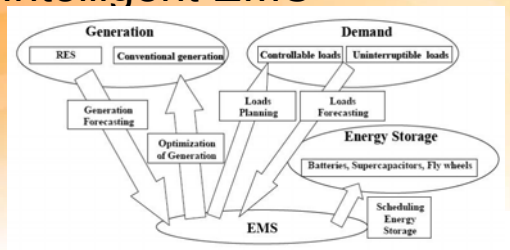


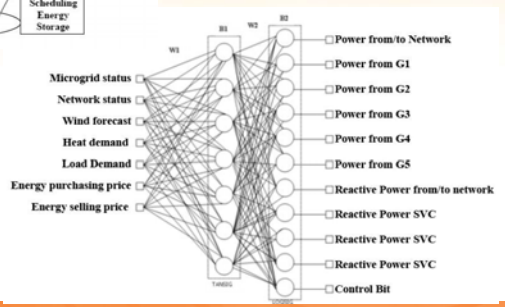
Image from Autonomous Systems and Intelligent Agents in Power System Control and Operation, Christian Rehtanz, (c) 2003 Springer-Verlag Berlin Heidelberg, p. 263

Intelligent EMS

- Implementation of Energy Management System (EMS) using a Multi-Layer Perceptron Neural Network
- G. Celli, F. Pilo, G. Pisano and G.G. Soma, "Optimal Participation of a Microgrid to the Energy Market with an Intelligent EMS," 2005 Power Engineering Conference

Intelligent EMS





Agent-Based Management and Control of Power Systems

CSIRO

Commonwealth Scientific and Industrial Research Organization

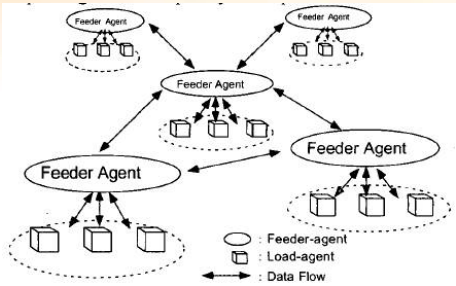
- Development of a multi-agent framework that can be used to form an aggregated response from a large number of DE resources and loads that is enough to create significant system benefits.
- Genetic algorithm techniques were used to plan the operation of loads and generators.

Power System Protection

- Giovanini etal, "A Primary and Backup Cooperative Protection System Based on Wide Area Agents," IEEE Transactions on Power Delivery, Volume 21, Issue 3, July 2006

Distribution Network Restoration

- Nagata, etal, "A Multi-agent Approach to Distribution System Restoration," The 47h IEEE International Midwest Symposium on Circuits and Systems, 2004



Other applications

- Autonomous Systems and Intelligent Agents in Power System Control and Operation by C. Rehtanz
  - Power system disturbance diagnosis
  - Coordination of FACTS
  - Coordination for secondary voltage control
  - Power system visualization

END

Thank you for your time