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?

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)
  - Loads
  - Intermediate storage

Centralized; hierarchical
Decentralized; distributed

MGCC
Introduction

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

Grid-connected operation

Island operation

Research highlights

- Control philosophies
- Energy management
- Microsource and load issues
- Analysis tools

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

EU, USA, Japan and Canada

The Microgrids Project (EU)

- 2002-2005
- The Consortium:


Successful Results

- “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”

More Microgrids

- 2006 – 2010
- 8.5 M€ budget
- Consortium


1Overview of Microgrid research and development activities in the EU, Manuel Sanchez, Montreal 2006 – Symposium on Microgrids
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 of Regional Power Grids with Various New Energies (2003-2007)

Canada Microgrid Research

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

Canada Microgrid Research

- Microgrid Case Studies
  - Remote microgrid
  - Utility microgrid
  - Intentional island network

Management and Control of Microgrids

Technical Challenges

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

Market and Regulatory Challenges

- 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

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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 et al: NN-based EMS

CERTS/UW-M for CEC-DOE

- Autonomous Control of Microsources
  - 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/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

- 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

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:

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

![A typical demand bid formulation](chart.png)

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

Decentralized Control

- **Forecasting Functions**
  - Electricity and heat demand
  - RES production
  - Electricity prices

- **Security Assessment Functions**

![Chart](chart.png)

Agent-based distributed control

- Hatzigryriou & Dimeas, “Operation of a Multi-agent System for Microgrid Control”
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)

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

Symmetrical assignment problem
- Match N pairs of persons and objects while maximizing the total benefit
  \[ b_{ij} = \text{benefit of assigning buyer } i \text{ to object } j \]
  \[ b_{ij} = \text{value of object } j \text{ to buyer } i - \text{cost of object } j \]
- 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

Implemented using Java Agent Development Framework (JADE)
- Number of agent pairs is limited by the maximum number of iterations (e.g. 105 iterations \( \rightarrow \) 15 agent pairs)
- \( @ 250 \text{ Wh per market agent block} \rightarrow 3.75 \text{ kWh} \)
Decentralized Control 2

Oyarzabal et al.

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

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

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

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)
- MGA is adapted from Strategic Power Infrastructure Defense System
- Subsumption architecture
Intelligent EMS

- Implementation of Energy Management System (EMS) using a Multi-Layer Perceptron Neural Network

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

Distribution Network Restoration

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

Thank you for your time