An Introduction to Microgrid for Integrated Distributed Generation and Energy Efficiency Applications

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Microgrid

- Microgrid is a part of the electrical power distribution network with:
  - Multiple Distributed Energy Resources (DER)
  - Multiple loads
  - The capability of islanding and operating independently from the grid
1. Generation Candidates for a Microgrid: Renewable & Non-Renewable DERs

- Solar Panels
- Wind turbines
- Marine energy
- Geothermal
- IC engines
- Biomass
- Fuel cells
- Microturbines
- Plug-in hybrid
- Battery
**Back-up and Storage Options**

Microturbines

- Large Sodium Sulfur (NAS) batteries have been deployed in Japan, Europe and USA.
- High energy content, moderate cost (US $2,000/kW) and 15-yr life make these attractive for grid-connected applications.
- Round-trip effy. 75-80%
- Storage: 6 hours
- Response time: 2 msec
- High temperature (300 deg C) and fire hazard are concerns.

**Electric Utility Scale Storage**

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2. Demand Aspects of a Microgrid:
Consumer Participation and Demand Response

- In a microgrid, the consumer will be an integral part of the grid.
- Opportunities for demand response, real-time pricing, outage detection, remote connect/disconnect and improved customer information are available through:
  - Smart appliances
  - Intelligent circuit breakers

3. Communication Aspects of a Microgrid: Integrated Communications

- There are a variety of communication media in use in the electric power system.
  - Power line carrier
  - Broadband over power line
  - LAN/WAN/Internet
  - Wireless radio system
  - WiFi 802.11b (range a few 100 meters; speed 5-10 Mbps)
  - WiMAX 802.16 (range 10-30 miles; speed 75 Mbps)
  - ZigBee/IEEE 802.15.4 (for automated metering system)
4. Control of a Microgrid

- Key technologies may include:
  - Sensing, metering and measurement
    - Wireless & intelligent sensors (including AMR/AMI)
  - Advanced control method
    - Agent and multi-agent systems
    - Substation automation
    - Distribution automation
  - Decision support and human interfaces
    - Visualization tools

Microgrid Physical and Cyber Layers
Microgrid can be used to provide load-generation balance at the local level.

Solar Energy Sources are Highly Variable

Output from an 8MW solar PV panel in Colorado on 9/4/08

- 81% drop in 5 minutes
- High variability due to clouds

Demand Response must be integrated

Source: US Dept of Energy
Stabilization of Wind Generation Outputs by Battery Energy Storage System

- Output fluctuations of Wind
- Constant output from Wind Gen. and BESS
- Charge and discharge to match output of wind generation

Application:
- Futanata Wind farm in Rokkasho Village
- Generators: 1.5 MW × 34 Units
- NAS Battery: 2.0 MW × 17 Units

Source: Yokoyama

Plug-in Hybrid Electric Vehicle as a Storage Option in the Microgrid
A plug-in hybrid electric vehicle (PHEV) is a hybrid vehicle with batteries that can be recharged by connecting a plug to an electricity outlet.

20-40 kWhr of Storage Available
Implementation of the Microgrid Concept

**Intelligent Distributed Autonomous Power Systems (IDAPS)**

- IDAPS is a specialized microgrid for coordinating customer-owned distributed energy resources (DERs), including both residential and commercial customers.

![Diagram of IDAPS microgrid with stages: Generation, Transmission, 138 - 69 kV Switchyard, Sub-Transmission, 69-12.47 kV Switchyard, and IDAPS microgrid highlighted]
IDAPS Multi-Agent System

- The key element of the proposed IDAPS microgrid is the cyber layer that controls loads and DERs, and provides “intelligence” to the microgrid.

- IDAPS agents can be defined as a collection of heterogeneous computational entities, each with its own problem solving capabilities and the ability to interact to reach an overall goal.
  - During normal operation:
    * Control both load and generation
    * Perform load management
  - During outages:
    * Shed loads based on their pre-determined priority
    * Secure critical loads and maintain network stability

- IDAPS agents are designed based on a well-known IEEE standard on Foundation for Intelligent Physical Agents (FIPA).

Steps used to Design the IDAPS Multi-Agent System

Step 1: Agent specification
Define agent architecture and number of agents

Step 2: Application analysis
Define agent roles, responsibilities and their interaction in the context of an intelligent grid

Step 3: Application design
Define ‘Facts’ - statements that agents believe to be true - and map agent responsibilities to the problems that each agent attempts to solve

Step 4: Application realization
Create generic agents capable of performing roles and responsibilities defined above
Step 1: Agent Specification

Define agent architecture and number of agents

- The idea behind the IDAPS multi-agent system is to break down a complex problem handled by a single entity into smaller and simpler problems handled by several entities.
- The IDAPS multi-agent system comprises four types of agents:
  - Control agent
  - DER agent
  - User agent
  - Database agent

![IDAPS agent architecture](image)

Step 2: Application Analysis

Define agent roles and responsibilities in the context of an intelligent grid

- Control agent
  - Detects contingency situation or grid failures
  - Controls and isolates the microgrid during emergencies
- DER agent
  - Stores and monitors DER information, i.e. ID, type, location, generation capacity and fuel availability
  - Controls DER power levels and ON/OFF status
- User agent
  - Provides real-time electricity usage and generation
  - Sheds loads based on a pre-defined priority
- Database agent
  - Records all messages and data shared among agents
Step 3: Application Design

Define ‘Facts’ and map agent responsibilities to the problems that each agent attempts to solve

- ‘Facts’ represent statements that an agent believes to be true. In the IDAPS environment, facts are:

<table>
<thead>
<tr>
<th>Facts</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Island mode</td>
<td>True/False</td>
</tr>
<tr>
<td>Energy</td>
<td>kWh</td>
</tr>
<tr>
<td>Load circuit breakers</td>
<td>Close/Open</td>
</tr>
<tr>
<td>DG operating cost</td>
<td>c/kWh</td>
</tr>
<tr>
<td>Real-time electricity price</td>
<td>c/kWh</td>
</tr>
<tr>
<td>Power requirement at loads</td>
<td>kW</td>
</tr>
<tr>
<td>Power produced by DERs</td>
<td>kW</td>
</tr>
<tr>
<td>DER status</td>
<td>On/Off</td>
</tr>
</tbody>
</table>

Step 4: Application Realization

- This step involves creating generic agents capable of performing roles and responsibilities defined previously.
- To demonstrate that the proposed multi-agent system can facilitate the seamless transition from grid-connected operation to an island mode, the following simulation is performed.
The Simulation

In this setup, agents will:
- Detect an upstream outage
- Disconnect a circuit breaker
- Control loads to match local generation

Simulation Results

Voltage and current at the load (per unit):

- **Voltage:**
  - Grid Connected Mode
  - Islanded Mode

- **Current:**
  - DG fault current is limited by the inverter rating.

The agent detects a fault and disconnects the CB after 1/2 cycle.
Summary

- This talk presents the design and implementation of the multi-agent system for use in an intelligent microgrid at the customer level.
  - A real-time simulated case study indicates that the multi-agent system can disconnect and stabilize the microgrid during emergencies.

- It illustrates the capability of a multi-agent system as a technology for managing the microgrid operation.
  - Perform load & generation control
  - Shed loads according to a predefined prioritized list
  - Serve as a flexible protection alternative

- Agent’s timely response demonstrates its ability to serve as a software alternative to a traditional hardware-based zonal protection system for isolating a microgrid.
  - This will allow the redefinition of the microgrid zonal boundary on the fly.

Is the Microgrid a Smart Grid?
Characteristics of a Smart Grid

- Enables active participation by consumers
- Accommodates intermittent generation and storage options
- Enables new products, services, and markets
- Integrates electric vehicles into the distribution network
- Provides power quality for the needs of a digital economy
- Anticipates and responds in a self-healing manner
- Operates resiliently in disasters, physical or cyber attacks

Source: EnerNex
The Microgrid as a Building Block of a Smart Grid

A microgrid is an islandable part of a power delivery system that:

- Serves one or more consumers
- Incorporates DERs and/or includes one or more points of connection to a large power system
- May range in size from a city block to a small city

Source: California Distributed Energy Resource Guide (picture - left)
EPRI - Electricity Technology Roadmap: 2003 Summary & Synthesis (MG definition)

The Smart Grid will be Realized at the Microgrid Level and then Aggregated

1. Power Infrastructure

2. Information Infrastructure

Source: EPRI
Thank you for Your Attention

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