Microgrids
– Future of the Power System?

Presented by:
Yazhou (Joel) Liu, Ph.D., PE
Schneider Electric Engineering Services
Yazhou.liu@us.schneider-electric.com
Outline

- What is Microgrids?
- Why Microgrids?
- Microgrids Development History
- Market Segment and Key Players
- Technology Challenges
- Schneider Electric Case studies
- Conclusion
Schneider Electric at a glance:

- 145,000 Employees
- ~28,000 North America

Diversified end markets – FY 2012 sales¹

<table>
<thead>
<tr>
<th>Market</th>
<th>Sales Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilities &amp; Infrastructure</td>
<td>20%</td>
</tr>
<tr>
<td>Industrial &amp; machines</td>
<td>24%</td>
</tr>
<tr>
<td>Data centers</td>
<td>17%</td>
</tr>
<tr>
<td>Non-residential buildings</td>
<td>30%</td>
</tr>
<tr>
<td>Residential</td>
<td>9%</td>
</tr>
</tbody>
</table>

The global specialist in Energy management

Making energy:
- Safe
- Reliable
- Efficient
- Productive
- Green

Use or disclosure of data contained on this sheet is subject to the restriction on the cover of this document.
Definition of Microgrids

An integrated energy system consisting of interconnected loads and distributed energy resources which as an integrated system can operate \textit{in parallel} with the grid or in an intentional \textit{islanded} mode.
Major Components of Microgrids

- **Energy Supply System**
  - Distributed Generation (like renewable sources, small combustion turbines)

- **Energy Storage Capacity**
  - Like Batteries, thermal storage

- **Demand Response and Efficiency Measures**
  - Minimize overall Energy use
  - Reduce non-critical load when operating in isolation

- **Energy Management Systems**
  - Maintain Balance and Stable Systems
  - Real-time response, Predictive and Forecasting analysis

- **Utility Grid Interconnection**
Typical distributed generations of Microgrids

- Renewable
  - PV
  - Wind
  - Small hydro
  - Biomass Plant

- Non Renewable
  - Emergency Generator
  - MicroTurbine
  - Fuel Cell
Why Microgrids?
- Reliability and Energy Security

- Southwest Army base served by two feeders
- May 2002 forest fire takes out both feeders
- Base down for 16 hours
  - Est. cost $3M
  - Loss of mission capability
- Southwest semiconductor plant served by two feeders
- Forest fire takes out both feeders
- Chip fab shuts down for 3 months
  - High-value customers cancel orders due to delay
  - Economic loss forces plant to shut down permanently

Courtesy of Sandia National Laboratories
Why Microgrids?

- **“Supply Surety”**, especially at mission-critical and outage-sensitive facilities
  - Military and government installations;
  - Institutional campuses (universities, hospitals, prisons);
  - Data centers;
  - Communities that repeatedly endure extended outages (NE, Florida, etc)

- **Social Policy**, Environmental liability, jobs/economic development in various jurisdictions – states, cities, and economic development zones
  - Renewable mandates;
  - Environmental constraints;
  - Sustainable/domestic fuel preferences
  - Local self-reliance

- **Transmission congestion**;

- **Economic competitiveness**;

- **Only option to have power for remote areas.**
Microgrids – from research to real world application

Definition of Microgrids
Prof. R. Lasseter

Early adopters – Real work applications

SPIDERS program, Security becomes important

Late 1990s Early 2000s Mid 2000s 2010

Future – take off?

---

Research Phase
A lot of funding from government into micro-grid; US, Europe, Japan, China. For example, CERTS in US, 5th and 6th frame in Europe

Research type real world applications for example, UCSD, CERTS Microgrids test bed,

Industry applications; Military, schools, remote off-grids, commercial/industry, etc.

CERTS - Consortium for Electric Reliability Technology Solutions;
SPIDERS - Smart Power Infrastructure Demonstration for Energy Reliability and Security;
Key Players & Key Market Segment
Market Size – from Forbes

**Total** Microgrid Distributed Generation Vendor Revenue, Average Scenario,
World Markets: 2012-2018

(Source: Pike Research)

Market Segments

Campus / Institutional
$ 4.0 Billion
20% Growth

Military
$ 1.5 Billion
35% Growth

Remote “Off-Grid”

Community / Utility

Commercial / Industrial

Market Growth

Market Size

Press ‘Esc’ to Return to Menu Slide
Active Microgrids Players

- Boeing
- Honeywell
- Lockheed Martin
- IBM
- Siemens
- Eaton
- GE
- Schneider Electric
- Alstom
Technical Challenges
Technical Challenges

● Typical Grid-Powered System Characteristics:
  ● “Rock-solid” voltage and frequency for grid-powered systems
  ● No need to worry about control and dispatch of normal-power generation assets – this is done by the utility
  ● When things go wrong, lots of energy is available from the grid to make the system “behave” in an unusual manner that is usually not difficult to detect – for example, short-circuits (Protection)
  ● Usually no need to worry about system stability
  ● Not many power electronic equipment, which can cause power quality issue.

● None of these are necessarily true for Microgrids!
● Cyber security
Conventional Generation

- Synchronous Generators – The mainstay of the conventional power grid
  - Over 1000GW of net conventional generation capacity in US Power Grid
Conventional Generation

- “Conventional” Electric Power User Scenario = Utility Power

Utility = 60HZ, 1.0 pu Voltage

1000 GW Capacity

Supply and Demand are Automatically Balanced (from User’s perspective)

User’s Utility Service

10,000 kW

10,000 kW Load

Critical Load = 1500kW
Conventional Generation

- Utility + User’s Paralleled Conventional Generation

Utility = 60HZ, 1.0 pu Voltage
1000 GW Capacity

Supply and Demand are Automatically Balanced (from User’s perspective)

Critical Load = 1500kW

- User’s Utility Service
- User’s Conventional Generator

User’s Generator can provide power up to its rating

10,000 kW Load

10,000 kW

8,000 kW

2,000 kW
Conventional Generation – Loss of Utility

Utility = 60HZ, 1.0 pu Voltage
1000 GW Capacity

Supply must be controlled to match demand – accomplished with generator governor

Usually all but “critical” loads are shed

1,500 kW Load

User’s Generator can provide power up to its rating
Load = 1500kW
Conventional Emergency System

- Changes in load can and will cause voltage and frequency variations.

Generator must adjust prime-mover input power to match load change. Frequency will dip as load is added – rate of change of frequency is proportional to mismatch in power into and out of the generator.

Utility = 60HZ, 1.0 pu Voltage
1000 GW Capacity

Voltage and Frequency will experience “transient” fluctuation

User’s Utility Service

1,500 kW Load + 500 kW sudden addition

User’s Generator can provide power up to its rating
Load = 1500kW
Conventional Emergency System

- Traditionally used for only emergency or critical load continuity
- Typically require shedding of load to match generation capacity
- Control is typically contained within the generators and generator control system
- Voltage and frequency fluctuate as load varies
- Performance can be improved by raising Generation Capacity relative to load
  - This can be in the form of larger generators or a larger prime mover matched to the same size alternator
  - Ratio of generation capacity to load depends upon ratio of prime mover to alternator ratings
- Run time limited by fuel source
Alternative Energy Sources – PV & Wind

- Variable source of energy – there when it is there, not when it’s not!
- Typically connected to the grid via an inverter
  - Allows DC power output to be connected to the AC electricity grid
  - Inverter typically acts as a current source – voltage and frequency are established by the grid
- Not suitable for large-scale stand-alone operation
Alternative Energy Sources – Batteries

- Derives energy from chemical reaction
  - Limited run time due to fixed amount of energy storage
- Wide range of technologies and operating characteristics
- Typically connected to the grid via an inverter
  - Allows DC power output to be connected to the AC electricity grid
  - Can respond to fast-changing loads
- Suitable for stand-alone operation – but run time is limited
Alternative Energy Sources – Fuel Cell

- Derives energy from chemical reaction
  - Fuel + Oxygen $\Rightarrow$ DC voltage + Heat
- Base-load device – runs best at constant power output
  - Output power ramp-up rate is limited
  - Unit can ramp down quickly (idle mode)
- Typically connected to the grid via an inverter
  - Allows DC power output to be connected to the AC electricity grid
  - Inverter can act as current-source (grid-parallelizing) or voltage-source (stand-alone)
- Stand-alone operation requires means of accommodating limited power ramp-up rate
Alternative Energy Sources - Variable

- Utility + Paralleled Variable Alternative Energy Source

Utility = 60HZ, 1.0 pu Voltage
1000 GW Capacity

Supply and Demand are Automatically Balanced (from User’s perspective)

10,000 kW Load

User’s Utility Service

8,000 kW

10,000 kW

Variable Power
Load = 1500 kW

User’s Variable Alternative Energy Source

2,000 kW
Alternative Energy Sources – Variable Loss of Utility

- Typically no microgrid capability with a variable alternative energy source alone!

Utility = 60HZ, 1.0 pu Voltage
1000 GW Capacity

Alternative Energy Source Goes Offline due to Loss of Utility Voltage

Facility is in the dark

User’s Variable Alternative Energy Source (Solar or Wind)

Load =
Alternative Energy Sources – Base Load

- Utility + Paralleled Base-Load Alternative Energy Source

Utility = 60HZ, 1.0 pu Voltage

1000 GW Capacity

Supply and Demand are Automatically Balanced (from User’s perspective)

User’s Utility Service

10,000 kW

8,000 kW

10,000 kW Load

2,000 kW

User’s Base-Load Alternative Energy Source (Fuel Cells)

10,000 kW Load

Constant Power Load = 1500 kW
Alternative Energy Sources – Base Load

Loss of Utility

- This works as a microgrid...

Utility = 60HZ, 1.0 pu Voltage

1000 GW Capacity

0 kW

User’s Utility Service

Supply power ramp rate is limited

2000 kW

User’s Base-Load

Alternative Energy Source
(Fuel Cells)

Usually all but “critical” loads are shed

2,000kW Load

Constant Power Load = 15kW
Alternative Energy Sources – Base Load Loss of Utility

- ...but load swings outside the capabilities of the fuel cells will cause shutdown

Utility = 60HZ, 1.0 pu Voltage

1000 GW Capacity

0 kW

Alternative Energy Source Goes Offline Due to load swings

Facility is in the dark

User’s Utility Service

Load = 1500 kW

User’s Base-Load Alternative Energy Source (Fuel Cells)
Alternative Energy Sources - Battery

- Utility + Paralleled Batteries

Utility = 60HZ, 1.0 pu Voltage
1000 GW Capacity

Up to 12,000 kW

Supply and Demand are Automatically Balanced (from User’s perspective)

10,000 kW

User’s Utility Service

Up to 2,000 kW for Battery Charging

10,000 kW Load

Energy Storage Load = 15

User’s Battery/Inverter System
Alternative Energy Sources – Battery Loss of Utility

- This works as a Microgrid...

Utility = 60HZ, 1.0 pu Voltage
1000 GW Capacity

0 kW

User’s Utility Service

Supply must be controlled to match demand accomplished using inverter controller

1,500 kW

User’s Battery/Inverter System

Usually all but “critical” loads are shed

1,500 kW Load

Controlled Power Output

Load = 1500 kW
Alternative Energy Sources – Battery Loss of Utility

- ...but cannot operate indefinitely!

Utility = 60HZ, 1.0 pu Voltage
1000 GW Capacity

Battery System Goes Offline due to discharge of batteries
Facility is in the dark

User’s Utility Service

User’s Battery/Inverter System

Discharged
Load = 1500 kW
Microgrids with Alternative Energy Sources

- Desirable due to operating economics – OpEx for renewable energy sources is extremely low compared to conventional generators
- Desirable due to positive environmental impact at site of operation
- Typically not possible using Alternative Energy Sources Alone

The solution (until the perfect alternative energy source comes along):
  - Combine alternative and conventional sources
  - Utilize energy storage (variable sources such as PV, wind) and/or variable loads (base-load sources such as fuel cells) to minimize the impact of source or load variability
  - Typically requires “plant controller” to dispatch energy sources and control loads
Microgrid – Conventional Generation + Variable Alternative Energy Source

- This arrangement is stable

Generator is forced to supply base load plus variable power

Voltage and Frequency will experience “transient” fluctuation

User’s Conventional Generator

User’s Variable Alternative Energy Source

User’s Generator can provide power up to its rating

Load = 1500kW
Microgrid – Conventional Generation + Variable Alternative Energy Source

- But too much variable source contribution leads to instability

- Generator cannot provide enough power to cover swings in variable power output

- System is unstable

1,500 kW Load

User’s Conventional Generator

User’s Generator can provide power up to its rating

Load = 1500kW

User’s Variable Alternative Energy Source

Variable Power

1400 kW

1,500 kW

100 kW
Microgrids – Conventional Generation + Variable Alternative Sources

- Operating economics dictate that variable component be as large as possible compared to conventional component.

- Allowable ratio of variable to conventional source components ("penetration") is dependent upon capabilities of conventional generator source:
  - Generally 10% - 20%
  - Subject of numerous studies – EPRI, NREL, others
  - Some researchers say about 25%, an interesting research area, power researchers use computer simulation to study this.

- Performance can be improved and allowable penetration can be increased by using energy storage:
  - Requires dispatch controller to regulate energy storage operation.
Microgrid – Conv+Variable+Storage

- This arrangement can be made to operate in a stable manner

Voltage and Frequency fluctuations are reduced

Energy Storage must be dispatched as required

0 kW

300 kW

User’s Variable Alternative Energy Source

Variable Power

1,500 kW

User’s Conventional Generator

1,200 kW

Up to 300kW As req’d

1,500kW Load

User’s Battery/Inverter System Controlled Power Output
Control & Cyber security

– another important parts of Microgrids

Sources: (1) U.S. Department of Energy
(2) Microgrid Institute
Schneider Electric Case Studies
U.S. DOE Solar Decathlon

**Location**
Washington, D.C. USA 2011

**Scope of Work**
As a sustaining sponsor, design build and operate the interconnected Net Zero Microgrid
- 74% renewable energy penetration
- 19 homes, 20,000 attendees
- 187 kW peak load
- Built to IEC, NEC, and NFPA std.
- 87 kW peak export to utility
- .5% voltage regulation
- Temporary operation
- One of 5 sustaining sponsors since 2009
- Irvine CA sponsored 2013

**Investment**
Sustaining Sponsor

**Impact**
Flawless net zero microgrid
Solar Decathlon Microgrid 2011
Conclusion

- Microgrids – a new concept being implemented in many places;
- A system includes distributed generation, advanced control, and possibly cybersecurity;
- Energy reliability, surety,
- Market data predicts a rapid growth of Microgrids;
- Next big thing – Microgrids?
Thank you!

Questions?

Contact:
Yazhou (Joel) Liu, Ph.D., PE
Schneider Electric Engineering Services
Yazhou.liu@us.schneider-electric.com
408-228-2579