The SMART Grid – Challenges and Directions

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August 10, 2016
Electric Power Systems

- The purpose of a power system is to generate power, transmit this power and to distribute it to customers at voltage levels and reliability that are appropriate to various users.
Electric Power Systems
Changing Values of Critical Infrastructures

- “...the nation is so dependent on our infrastructures that we must view them through a national security lens. They are essential to the nation’s security, economic health, and social well being.” President’s Commission on Critical Infrastructure Protection 1999

- Most infrastructures depend on energy for operation
  - telecom, water, transportation, government, health, agriculture
  - making energy assurance of local and regional importance

DEPARTMENT OF ENERGY
2006 Strategic Plan

DEPARTMENT OF DEFENSE
Quadrennial Defense Review Report

DEPARTMENT OF HOMELAND SECURITY
2008 Plan for Protecting Critical Infrastructure

More flexible, reliable, cost and energy efficient, sustainable and secure energy supplies
Critical Infrastructure Protection Changes in System Performance Metrics

- Normal Environment
  - Normal Input
  - Desired Output
  - Function
    - Malfunction
      - Non-normal Input
      - Undesired Output
      - Non-normal Environment

Compliance-based: High probability, low consequence
Performance-based: Low probability, high consequence
Emerging Energy Assurance Concerns

Electric Power Outage Intensity in the U.S.
Customers affected has increased by a factor of three per outage
Power Outages Can be Regionally Significant

Major outages are lasting for 5-14 days, but these duration electric power outages are not commonly designed for
New Energy System Design Definitions

- **Energy security**
  - Public Law 112-81 - “The term ‘energy security’ means having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet mission essential requirements.”

- **Mission assurance**
  - Public Law 112-81 - “.prioritized to provide power for assets critical to mission essential requirements on the installation in the event of a disruption.”
  - DODD 3020.40 - Mission assurance. “A process to protect or ensure the continued function and resilience of capabilities and assets—including personnel, equipment, facilities, networks, information and information systems, infrastructure, and supply chains—critical to the execution of DoD mission-essential functions in any operating environment or condition. ”

- **Energy resilience**
  - Presidential Policy Directive 21 - “Resilience is the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.”
  - Army new ES3 - “Resilience: The capability for systems, installations, personnel and units to respond to unforeseen disruptions and quickly recover while continuing critical activities.”
  - DHS 2013 – “Resilient infrastructure assets, systems, and networks must be robust, agile, and adaptable. Mitigation, response, and recovery activities contribute to strengthening critical infrastructure resilience.”
## Electric Grid Assurance Strategies

<table>
<thead>
<tr>
<th>Component Hardening (Protection)</th>
<th>Increase Component Redundancy (Mitigation)</th>
<th>Accelerate Outage Response (Response &amp; Recovery)</th>
<th>Distributed Resources (Mitigation, Recovery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harden substations – guards, guns, gates, barriers</td>
<td>Redundant transmission lines</td>
<td>Real-time monitoring of substations and transmission lines</td>
<td>Distribution switch gear improvements to more easily move power around</td>
</tr>
<tr>
<td>Harden substation equipment</td>
<td>Redundant substations</td>
<td>Fast response, fast reconstruction</td>
<td>Local energy generation</td>
</tr>
<tr>
<td>Harden transmission and distribution lines</td>
<td>Increase connectivity</td>
<td>Maintain spares, extra equipment, pre-planned work around</td>
<td>Renewables and/or alternative fuels</td>
</tr>
<tr>
<td>High costs, events beyond design basis</td>
<td>High costs, regional outage issues</td>
<td>High costs, regional outage issues</td>
<td>Medium costs, outage duration issues</td>
</tr>
</tbody>
</table>
Energy Assurance Challenges
Energy Assurance Strategy Concerns

- Army base served by two feeders
  - Hurricane takes out both feeders
  - Base down for 16 hours
    - Est. cost $3M
    - Loss of mission capability

- Semiconductor plant served by two feeders
  - Forest fire takes out both feeders
  - Chip fab shuts down for 6 months
    - High-value customers cancel orders due to delay
    - Economic loss forces plant to shut down permanently

Regional outages, slow repair, remote locations impact options and costs
Today’s Power Grid is Limited in the Ability to Easily Meet New Energy Assurance Requirements

- Fuel storage not on load side of system
- Fixed infrastructure is less flexible
- Several failure points in long systems
General attributes of the Smart Grid were defined in the Energy Independence and Security Act of 2007

“..which together characterize a Smart Grid:

(1) Increased use of digital information and control technology to improve reliability, security, and efficiency of the electric grid,

(2) Dynamic optimization of grid operations and resources, with full cyber-security,

(3) Deployment and integration of distributed resources and generation, including renewable resources,

(4) Development and incorporation of demand response, demand-side resources, and energy-efficiency resources,

(5) Deployment of “smart” technologies...for metering, communications concerning grid operations and status, and distribution automation

(6) ...smart appliances...

(7) ...advanced electricity storage,

(8) ...consumer timely information and control options,

(9) Development of standards for communication and interoperability of ... equipment connected to the grid, including the infrastructure serving the grid,

(10) Identification and lowering of unreasonable barriers to adoption of smart grid technologies, practices, and services.”

Missing attributes of Safety and Cost Effectiveness
NYC After Tropical Storm Sandy

Energy assurance designs at work
Advanced Microgrids To Support Smart Grid Initiatives

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanogrid</td>
<td>Less than 10-kW, single-phase, residential</td>
</tr>
<tr>
<td>Small microgrid</td>
<td>From 10-kW to 500-kW, typically three phase</td>
</tr>
<tr>
<td>Commercial microgrid</td>
<td>Greater than 1 MW up to 20MW</td>
</tr>
</tbody>
</table>

Ref EPRI
Mathematically - What is a microgrid?

<table>
<thead>
<tr>
<th>Grid Definition</th>
<th>Generation Size</th>
<th>Commonly Considered Size</th>
<th>Common Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. Grid</td>
<td>~1 Tera watt (1x 10^{12} watts)</td>
<td>1-200 kW</td>
<td>High to medium voltage, 12 kVa- 700 kVa</td>
</tr>
<tr>
<td>Microgrid</td>
<td>1 x 10^{-6} (US Grid) 1 x 10^6 watts ~1 MW</td>
<td>1 MW-20 MW</td>
<td>Medium voltage 4 kVa - 34 kVa, three-phase, 4-20 buildings</td>
</tr>
<tr>
<td>Nanogrid</td>
<td>1 x 10^{-9} (US Grid) 1 x 10^3 watts ~1 kW</td>
<td>1-200 kW</td>
<td>Low voltage 120/480 V, often single phase, 1-2 houses or buildings</td>
</tr>
</tbody>
</table>
## Functionality and Types of Microgrids

| **STANDARD MICROGRID** | ● Operates where there is no large grid or operates generally islanded from the larger grid  
|                       | ● Often used with a central power plant or CCHP plant to balance power supplies and demand locally (universities, industries)  
|                       | ● Minimal grid interaction or support |
| **ADVANCED MICROGRID** | ● Can operate islanded or grid-tied  
|                       | ● Can integrate distributed and renewable generation and manage and control power demand and distributed resource allocation  
|                       | ● Supports optimal use of distributed energy resources during both power outages and for grid support |
| **SMART GRID NODE**   | ● Same functional capabilities as an advanced microgrid  
|                       | ● Control capabilities to federate with other microgrids, if needed  
|                       | ● Grid-tied operations are coordinated through the grid operator to support grid operations and performance, and provide ancillary benefits to the grid |

Advanced microgrids are the building blocks for Smart Grid Nodes, which in turn is one of the major power utility building blocks for the Smart Grid.
How can Microgrids Help

- A standard solution (left) would require installing a minimum of two redundant generators at each building for redundant backup power or four new (red) 100 kW generators, each only supporting one building.
- A microgrid solution would require only one new (red) 200 kW generator at one of the buildings for redundant power:
  - Loss of any of the three generators would still be able to supply the 300 kW load required for the 3 buildings.
  - The combined resources in a microgrid can be used to support the grid.
Energy Surety Design Methodology

1. Define Design Basis & Threats (DBT)
2. Define Performance Goals & Objectives
3. Determine Consequences
4. Formulate Possible Solutions
5. Evaluate Performance

- Meet Objectives?
  - Yes: Implement
  - No: Iterate, Validate

- Analyze, Optimize

- Initial Assessment Phase
- Analysis Phase

- Make Changes and Reassess

- Identify Critical Loads and Infrastructure
- Characterize System & Define Boundary
## Example of Critical Municipal Services that Should be Considered

<table>
<thead>
<tr>
<th>Municipal Controlled Services</th>
<th>Community Controlled Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communications (Radio and Phone)</td>
<td>Telecommunications (cell towers)</td>
</tr>
<tr>
<td>Data Service / Internet</td>
<td>Community media (radio)</td>
</tr>
<tr>
<td>Local Emergency Response Coordination</td>
<td>Existing shelters - heat/cold</td>
</tr>
<tr>
<td>Regional E/R Coordination</td>
<td>Hospitals</td>
</tr>
<tr>
<td>Civil order</td>
<td>Assisted living services</td>
</tr>
<tr>
<td>Road Clearing / Management</td>
<td>Pharmacies/Medication supply</td>
</tr>
<tr>
<td>Equipment maintenance</td>
<td>Fuel (Natural Gas / propane / Gasoline / Diesel)</td>
</tr>
<tr>
<td>Emergency Services</td>
<td>Food / provisions</td>
</tr>
<tr>
<td>Potable Water</td>
<td></td>
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<tr>
<td>Waste Water</td>
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<tr>
<td>Flood Control</td>
<td></td>
</tr>
<tr>
<td>Temporary Housing / Shelters</td>
<td></td>
</tr>
<tr>
<td>Safety systems (lighting etc.)</td>
<td></td>
</tr>
</tbody>
</table>
Example Stakeholder Rankings of Critical Assets Needed for a 2-day and a 5-day Power Outage

<table>
<thead>
<tr>
<th>Asset</th>
<th>Building or Asset Name</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Public Works Garage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Fire Department - HQ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Police Department - HQ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>WTP + Low Lift Pump</td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td>WWTP</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>6</td>
<td>Radio Towers and System: Fire/Police</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>High School (Emergency Shelter)</td>
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</tr>
<tr>
<td>8</td>
<td>WWTP Flood Control System</td>
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<tr>
<td>9</td>
<td>Flood Control - Remote Sewer Pump System</td>
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<td></td>
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<tr>
<td>10</td>
<td>Municipal Building</td>
<td></td>
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<tr>
<td>11</td>
<td>Food and Gas</td>
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<td></td>
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<tr>
<td>12</td>
<td>Fuel Company</td>
<td></td>
<td></td>
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<tr>
<td>13</td>
<td>Cell Towers</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Building additions for a 5-day outage

Note: Stakeholders have different views of critical functions
Smart Grid Thoughts and Directions

- Better integration of neighborhood distributed generation and demand response into microgrids
  - Roof top solar, smart meters, pricing benefits
- Integration/networking of neighborhood microgrids to support regional energy assurance
  - 20-30 Smart Grid Nodes
- More focus on resilient critical circuits, critical services, critical infrastructures in homes, businesses, and communities
- Grid designs will transition to support faster recovery rather than focus on standard hardening and standard redundancy