Smart Grid – A Reliability Perspective

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Outline

- Smarter Grid
- Focus Areas
- Reliability Issues
- Architectural Approach
- Q/A
Smart Grid

- Utility industry has been utilizing communication and information technologies
- Increasing complexity of the grid, growing concerns for environment, energy sustainability, etc. accentuate the need for a quantum leap in application of such technologies
- This leap toward a “smarter” grid is referred to as “smart grid”
Smart Grid Vision

- Enhanced reliability
- Resiliency against malicious attacks
- Reduced emission and improved energy sustainability
- Enhanced efficiency and asset utilization
- Improved market efficiency
- Active consumer participation in managing their consumption and generation
- Higher quality of service
Smart Grid Deployment Trends

Focus Areas

- Reliability
- Renewable resources
- Demand response
- Electric storage
- Electric transportation

Above trends also highlighted in “FERC Smart Grid Policy Statement”
Reliability
Cost of Unreliability (2004 report LBNL-55718)

Summary of U.S. Cost of Power Interruption Sensitivity Cases

<table>
<thead>
<tr>
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<th>Surveyed Populations</th>
<th>Non-surveyed Populations</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>Power Outages</td>
<td>$46 billion</td>
<td>$58-118 billion</td>
<td>$104-164 billion</td>
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<tr>
<td>Power Quality</td>
<td>$7 billion</td>
<td>$8-17 billion</td>
<td>$15-24 billion</td>
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<tr>
<td>Total</td>
<td>$53 billion</td>
<td>$66-135 billion</td>
<td>$119-188 billion</td>
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Grid Reliability
Issues We Face

- “Insufficient” Investment in Grid and Load Growth
  - Contention for limited transfer capability
- Diversification of Energy and Storage Resources
  - Aggravating grid congestion and/or controllability
- Larger operating footprints
  - More complex problems
  - Smaller error margins
  - Shorter decision times
- More, larger and longer transfers
  - Volatility
  - Smaller margins
Increasing Demand
Consumption and Peak

- Increasing energy consumption and peak demand creating contention for limited transfer capability

- Resources required for the peak underutilized:
  - ERCOT:
    - Top 5% of capacity used less than 1% of time
    - Top 25% of capacity needed 10% of time
  - PJM hourly 2007 Load
    - Less than 85 GWh for 62.2% of the hours
    - Less than 100 GWh for 88.8% of the times
    - More than 130 GWh for only 15 hours.
Reduced Emission and Energy Sustainability
Challenges of Renewables Integration

- Intermittency
- Generation not align with load patterns
- Forecasts uncertainty
- Operational performance issues
  - Low system inertia
  - Voltage, congestion,…
  - Additional ancillary services
- Transmission
  - Large renewables are remote
Impact of 18 GW of wind on ERCOT’s 70+ GW system

Load and Net Load Duration Curves

- 2017 Load Duration Curve
- 2017 Net Load Duration Curve (18,456 MW Wind)

Existing Nuclear Generation: 4,900 MW
Publicly Announced Nuclear Projects: 9,200 MW
Existing Coal Generation: 15,700 MW
Publicly Announced Coal Projects: 3,800 MW

8,167 Hours
6,111 Hours
4,816 Hours

Sorted Hour
Hourly Load (MW)

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Managing the Load Profile
DR and Storage

- **Demand Response**
  - Non-emergency DR can reduce the need for additional resources
  - Automatic or manual response by consumer

- **Storage**
  - Various technologies
  - Centralized, Distributed, Behind the Meter, etc.

- *Both add to the complexity*
Electric Transportation
PEV, eCAR, etc.

- **Motivations**
  - Environmental
  - Reduce reliance on fossil fuels
  - Demand Response / Storage
  - Others

- **Challenges**
  - 200 miles range requires about 50kWh of battery energy
  - Charge time
    - Fast charge – “distribution congestion”
    - Slow charge – unacceptable life style
Ideally Successful Load Management Scenario

Higher Susceptibility to failure?

- Close coordination of all resources such as:
  - Demand response
  - Storage
  - Electric vehicles

- **Objective:**
  - Nearly flattened load profile
  - Initial improved reliability due to lower peak

- **“Unintended” Consequences Over Time:**
  - Grid operated closer to near-peak conditions most of the time
  - System pushed closer to its “edge” more often - higher susceptibility to failure due to:
    - Net load growth
    - Forces of optimal T&D asset utilization
Impact of 18 GW of wind on base-load generation

- **Existing Nuclear Generation:** 4,900 MW
- **Publicly Announced Nuclear Projects:** 9,200 MW
- **Existing Coal Generation:** 15,700 MW
- **Publicly Announced Coal Projects:** 3,800 MW

System Pushed to the “Edge”
Higher susceptibility to failure
IT Infrastructure for Smart Grid
Addressing Reliability Concerns

- Significant disturbances involve cascading events rapidly aggravated by uncoordinated local actions

- Maintaining a reliable system requires:
  - Coordinated response
  - Timely automated intelligent response
  - Secure IT infrastructure

- Harnessing modern communication and information technologies to enable:
  - Grid-wide coordinated monitoring and control capabilities to address:
    - Grid operated much closer to its limits more often
    - A more volatile and qualitatively different operating environment
    - Automated on-line analyses for real-time decision making (to replace the inadequate off-line studies)
  - Fail-proof and timely bidirectional communications at all levels
  - Processing more data, more automation, more control
IT Infrastructure for Smart Grid

Distributed Intelligence

- Centralized systems are too slow for this purpose
- Need distribution of intelligence throughout infrastructure to enable:
  - Local data processing to minimize need for massive data exchanges, e.g. at substation level:
    - Bad data detection
    - Feeder level forecasts
  - Timely local intelligent actions coordinated with higher level analysis
    - Even sub-second response is feasible with modern technology
- Need a better coordinated, higher performance Monitoring & Control Infrastructure
  - “Pervasive”, “Grid-wide/T&D”, “Timely”, “Secure”, “super EMS”…?
Distributed Autonomous Architecture
Coordinated hierarchical intelligence

- Timely local control coordinated with global information

Centralized

Partially Distributed

Fully Distributed
Architectural Dimensions
Distributed Based on Grid Operational Requirements

- Distribution and coordination of functional tasks in a virtual hierarchy in three dimensions:
  - Organizational
    - Grid, Region, …Control Area,…Substation
  - Geographical
    - Region 1, Region 2, … j…
    - …. Substation 1, Substation 2,…n,
    - etc.
  - Functional
    - Forecasting
    - Alarming
    - Voltage control,
    - etc.
Geographical and Organization Dimension

Grid

National/Continental Interconnection

Regions

Region R1

Region Ri

Control Areas

Control Area A1

Control Area A2

Control Area A3

Control Area Ak

Substations

Substation S1

Substation Sm

Substation Sn

Integrated Messaging/Data
Conventional Functional Implementation: e.g. Grid Level

- **Grid**

- **Regions**
  - Region R1
  - Region Ri

- **Control Areas**
  - Control Area A1
  - Control Area A2
  - Control Area A3
  - Control Area Ak

- **Substations**
  - Substation S1
  - Substation Sm
  - Substation Sn

**Integrated Messaging/Data**
Distributed Functional Agents – Two Levels

Grid

Regions

Control Areas

Substations

Functional- Agent 1 @Grid

Function Component
Real-time Data component
Alarming component

Functional- Agent 1 @Regional

Function Component
Real-time Data component
Alarming component

Control Area A1  Control Area A2  Control Area A3  Control Area Ak

Substation S1  Substation Sm  Substation Sn
Distributed Functional Agents – All Levels

Grid

Regions

Control Areas

Substations

Substation S1

Substation Sn
Autonomous Intelligent Agents
Distribution of Functional Responsibilities

- Agents are deployed:
  - In a virtual hierarchy
  - On a grid-wide computing network
- Agents coordinate execution of functional tasks
  - Data Processing
  - Monitoring
  - Reliability Enhancements
  - Control
- Agents cover time scales ranging from Operational Scheduling through sub-second periods
Distributed Autonomous System

Function F1
(e.g. Voltage Stability, State Estimation)

Grid

Regions
Region R1
Region Ri

Intelligent Functional Agent for F1

Control Areas
Control Area C1
Control Area Ck

Intelligent Functional Agent for F1

Substations
Substation S1
Substation Sn

Intelligent Functional Agent for F1

Actuator
Temporal Dimension: Distinct Time Scales

- Hour-ahead
- 5-minute
- 1-minute
- 2-second
- 1-second
- 100-millisecond
- 10-millisecond
- “continuous”
Execution Cycles and Temporal Coordination

Grid
- Hourly Cycle
- 5 min cycle
- 1 min cycle
- 2 sec cycle

Region
- Slower cycles

Control Area
- Other Control Areas
- Hourly Cycle
- 5 min cycle
- 1 min cycle
- 2 sec cycle

Zone/Vicinity
- Faster cycles

Substation
- Other Substations
- 1 sec cycle
- 100 m-sec cycle
- 10 m-sec cycle
- Protection Systems

Lower Levels (Distribution, etc.)
Technical Feasibility
Enabling Technologies

- Better telemetry: PMUs - faster, time-stamped, accurate, sub-second scanning
  - Possible to limit the time skew to 1 millisecond or even less

- Faster control devices: Power electronics

- More robust controls: Adaptive protection and control settings

- Intelligent Embedded Devices (IEDs) to enable:
  - Equipment level fault diagnosis
  - Constrained operation
  - “Intelligent” RAS/SPS, etc.
  - Autonomous local control / restoration of equipment

- Enhanced computing capabilities supporting virtual hierarchical multi-agent environments

- Internet technology: to facilitate data exchange, process control and cyber security to implement Plug-and-play hardware and software components

- Integrated and secure communication infrastructure
  - Support a virtual hierarchy where location of HW, SW and data is transparent to the user
Industry Trends
Synergy with Current Practices

- Many of the smart grid technologies are already in place in various ad-hoc implementations:
  - wide-area monitoring and control
    - Phase angle and slow oscillation monitoring
    - Line thermal monitoring /dynamic rating
    - Geomagnetic disturbance recognition
  - Special protection schemes, as precursors of intelligent agents
    - Stability / Transfer Capability Enhancement
  - State estimation
    - PMU augmented state estimation
  - Forecasting
    - Multi-level
  - Infrastructure
    - Advanced Metering Infrastructure
    - PMU networks
    - Optical fibers connecting substations
Smart Grid

Conclusion

- Meeting reliability challenges is central to smart grid
- This requires a systematic approach to develop a common vision
- The proposed architectural framework is a concrete representation of such common vision
- This framework can be thought of as a “super EMS” consisting of a network of networks that allows for evolutionary implementation of the infrastructure.
- This vision facilitates a cohesive grid-wide integration of the enabling technologies and emergence of needed standards
Smart Grid
Architectural Paradigm for Transformation of the Grid

- An architectural approach is essential for transforming the power grid to a “smarter grid”

- It was not because of a few specific applications that iPhone revolutionized the “phone” but for its architecture that led to an explosion of functionality.