Smart Grid

Developments, challenges and trends

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Agenda

- **What is Smart Grid?**
- Smart Transmission Systems
- Smart Distribution Systems
- Challenges and trends
- Conclusions
What is Smart Grid?

“Smart grid” generally refers to a class of technology people are using to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation.

These systems are made possible by two-way communication technology and computer processing that has been used for decades in other industries.

They are beginning to be used on electricity networks, from the power plants and wind farms all the way to the consumers of electricity in homes and businesses.

They offer many benefits to utilities and consumers -- mostly seen in big improvements in energy efficiency on the electricity grid and in the energy users’ homes and offices.

http://energy.gov/oe/technology-development-smart-grid
What is Smart Grid?

- Smart Grid is a vision for electric utilities: Utilities, and consumers will accrue values through the convergence of power delivery, information technologies, communications, power electronics, and advanced automation, monitoring and control to achieve improved reliability, and increased efficiency and customer satisfaction.

- Applied to Generation, Transmission, Distribution and customer sectors by leveraging computer and communications infrastructure and technologies.

- The set and scope are unique to each utility, in the context of traditional capacity engineering and planning.
Smart Grid Business Drivers: New Business Environment

- Reliability & Quality of Supply
  - Renewable Resources & PHEVs
  - Greenhouse Gases
  - Operational Efficiency
  - Aging Workforce
  - Condition-Based Maintenance
- Carbon Footprint
  - Demand Response
  - Supply Reliability
  - Power Quality
- Productivity Improvement
  - Aging Infrastructure
Drivers – Reliability and National Security

NE-US – Can, 2003: 50M people
- 2 hours before disturbance
  500kV line disconnect
- Heavy power flow in region

- One 500 kV line sags into a tree and disconnects
- Heavy load 230+115 kV lines
- 230+115 kV lines disconnect due to overload
  - 345 kV lines trip

- Voltage declines and power units trip
  - Power oscillations and voltage decline cause cascading separations

Blackout occurred in 3 min.
System restored in ~1-2 days

https://reports.energy.gov/
Drivers – Renewable Portfolio Standards (RPS)

Source: NREL
Smart Grid Phases

- **Phase 1:** Developing a common understanding of what the smart grid is, and what applications and benefits are.
  - Holistic approach addressing operational, regulatory, and commercial drivers, all technical domains, and broad coverage of benefits.

- **Phase 2:** Deployment of a large number of implementation projects supported by multi-billion dollar investments.
  - Evaluate ‘real’ benefits and compare expectations with realized benefits.
  - Success of these deployment projects will set the direction for further steps in developing the grid of the future.

- **Phase 3:** Transitioning into “normal course of business”.
  - Results achieved and smart grid infrastructure deployed will uncover new applications and benefits.
Smart Grid Components for Effective Deployment

- Devise Deployment & Asset Mgmt
- Communication Network Ops & QoS Mgmt
- Real-time Power Sys Data Mgmt
- Engineering & Enterprise Integration

- Integrated Communication

- Distributed Energy Resources (DER)
- Network Automation
- Advanced Metering Infrastructure (AMI)
- Demand Response (DR)

- Front End Processor
- SCADA EMS/DMS
- Load Mgmt DR Apps
- Meter Data Mgmt
- DR Controls

- Utility Enterprise Integration Bus
  - CIS
  - ERP
  - OMS
  - WAMS
  - FFA/MWM

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Translated into Requirements

- Optimal utilization of infrastructure, increased efficiency and reliability, including auto-restoration (“self-healing”)
- Ability to integrate high penetration levels of Distributed Energy Resources (DER), particularly renewables
- Ability to integrate new loads, e.g., Plug-in Hybrid Electric Vehicles (PHEVs)
- Interface with Home Area Networks (HAN) to empower the customer
- Advanced monitoring, analysis, processing and control
  - Intelligent Electronic Devices (IEDs), AMI
  - Phasor Measurement Units (PMUs)
  - Advanced Utility Enterprise Systems (EMS, DMS, OMS, etc)
  - Robust and reliable communication infrastructure
  - Interoperability
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Synchrophasors are **precise grid measurements** using GPS signals - now available from monitors called phasor measurement units (PMUs)

As PMU measurements are **time-aligned** to a common reference, they enable a precise and comprehensive view of the utility network or entire interconnection

- **PMU measurements are taken at high speed** (e.g. 30 - 120 observations per second) compared to one every 4 seconds w/ conventional technology

Enable a better indication of **grid stress**, and can be used to trigger control actions to **maintain reliability**
Large Scale Deployment of PMU Systems

Stringent and varied requirements
- High reliability and availability
- Accommodate all participants

Address both short and long term needs
- System expandability ➔ Number of measurements will grow over time including both synchrophasor and non-phasor data
- System flexibility and adaptability ➔ Start with small number of applications and add new in the future

Technology advancements and product development
- Standards development continues to evolve: NERC CIP; synchrophasor (IEC 37-118); cyber security; IEC 61850, etc.

System integration with other enterprise systems, such as EMS/SCADA, DMS, GIS
Example – WAMPAC

Wide Area Monitoring, Protection and Control
A MUST for **Smart Transmission Grid**

- Data Analysis and Visualization
  ➔ *Significant benefits achieved*

- System Reliability: Outage Reduction, Blackout Prevention
  ➔ *Huge societal benefit*

- System Operations and Planning, Modeling
  ➔ *Enables paradigm shift*

- Market Operations: Congestion Mgt. & Location Marginal Pricing
  ➔ *Large potential financial benefit*
Event and solution timescale

Uncoordinated vs. Coordinated Operation

- **Uncoordinated**
  - Protection
  - FACTS
    - Fast, direct local action

- **Coordinated**
  - System operation
  - Long term stability
  - Market transactions
  - SCADA/EMS
    - Steady state view
    - Slow action
  - Fast system contingencies:
    - Voltage & angular instability
    - Cascading
  - Wide Area Measurement, Protection, and Control (WAMPAC)
    - Dynamic wide area view
    - Fast coordinated action

Dynamic – real time vs. Steady state

- 0.01
- 0.1
- 1
- 10
- 100

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Before

First PMU

Analog Displays

Now

Standard feature
(relays, DFR, controllers, equip. monitors)

On major interconnections

Improved comm. infrastructure, including control

Standard SW tools included in EMS/SCADA

Interoperability standards deployed

2014

2018

Thousands of PMUs world-wide

Higher data rates

In Distribution

Fast Adaptive Protection

Integrated in standard business and operational practices

Distributed comm. architecture, fully integrated with EMS/SCADA
Agenda

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Smart Distribution Systems

- The distribution system is arguably the component of power delivery infrastructures that is being impacted the most by the implementation of the smart grid concept.

- The objective of smart distribution systems is to help attain the functional characteristics of the smart grid:
  - Auto-restoration (“self-healing”) from power disturbance events
  - Enabling active participation by consumers in demand response
  - Operating resiliently against physical and cyber attack
  - Providing power quality for 21st century needs
  - Accommodating all generation and storage options
  - Enabling new products, services, and markets
  - Optimizing assets and operating efficiently
Smart Distribution Systems

- Some of the changes on the distribution system driven by the smart grid are:
  - Implementation of advanced distribution automation
  - Increased participation and empowerment of customers
  - Higher level of real-time monitoring and control
  - Advanced Distribution Management Systems (DMS)
  - Active distribution systems with high penetration of Distributed Generation (DG), Distributed Energy Storage (DES), and new loads, e.g., PEVs
  - Increased efficiency via system optimization, e.g., VVO
  - Modern protection technologies, e.g., adaptive protection

- This evolution is leading to changes in the way distribution systems are planned, designed, built, and operated, e.g., closed-loop operation
Example – Distribution Automation

- It is not a new concept!
- There are many existing examples of automation on the distribution system
- This includes fully automatic – no man in the loop devices
Distribution Automation – not a new concept

Fuses, Protective Relays

Load Tap Changer

Reclosers, Sectionalizers

Switched Cap Banks

Today's Distribution System

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Distribution Automation – Smart Grid world

Fuses, Protective Relays

Load Tap Changer

Reclosers, Sectionalizers

Switched Cap Banks
Distribution Automation – Smart Grid world

- IEDs provide more intelligent control
- Distribution system operators (dispatchers) are kept informed

Protective Relays

Reclosers, Sectionalizers

Load Tap Changer

Switched Cap Banks

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Fault Location, Isolation, and Service Restoration

Use of automated feeder switching to:
- Detect feeder faults
- Determine the fault location
- Isolate the faulted section of the feeder
- Restore service to “healthy” portions of the feeder

When a permanent fault occurs, customers on “healthy” sections of the feeder may experience a lengthy outage

FLISR provides the means to restore service to some customers before field crews arrive on the scene
Fault Occurs

Customer Reports Outage

Travel Time

Fault Investigation & Patrol Time

Time to Perform Manual Switching

Feeder Back to Normal

Repair Time

POWER RESTORED TO CUSTOMERS ON HEALTHY SECTIONS OF Feeder

Without FLISR

FAULT OCCURS

Customer Reports Outage

Travel Time

Fault Located

Time to Perform Manual Switching

Feeder Back to Normal

Repair Time

POWER RESTORED TO CUSTOMERS ON HEALTHY SECTIONS OF Feeder

With FLISR

1 to 5 minutes

5 - 10 minutes

15 - 30 minutes

15 - 20 minutes

10 - 15 minutes

1 - 4 Hours

5 - 10 minutes

15 - 30 minutes

5 - 10 minutes

1 - 4 Hours

45 - 75 minutes
Example – Volt-VAr Control and Optimization

- Use of capacitor banks, voltage regulators, distributed generating units, static VAR compensator, and other devices
  - To maintain acceptable voltages at all points along the feeder under all loading conditions
  - To operate the distribution system as efficiently as possible without violating any load and voltage constraints
  - To support the reactive power needs of the bulk power system during system emergencies
How is it accomplished?

- **Traditional Devices for Volt-VAR Control**
  - Fixed and switched capacitor banks (in substation and out on the feeder)
  - Substation transformers with Load Tap Changers (LTCs)
  - Voltage regulators (in substation and/or out on the feeder)

- **“Future” Devices for Volt-VAR Control**
  - Distributed Energy Resources
  - Static VAr compensators
  - Distribution-class FACTS
Example – Advanced protection systems

- Large scale implementation of DG and advanced applications and technologies lead to situations in which the distribution network evolves from a “passive” (local/limited automation, monitoring and control) system to one that actively (global/integrated, self monitoring, semi-automated) responds to the various dynamics of the electric grid.

Distribution Grid ~ Transmission Grid

- Protective Relay
  - Over-current (50/51)
- Reclosers
- Sectionalizers
- Fuses

Microprocessor Relays:
- Multifunctional capabilities
- Automation, monitoring and control integration capabilities
- Setting zones
- Self-testing
- and other
Advanced protection systems

1. Fault
2. Fault detection
3. DGT-U sends transfer trip signal
4. DGT-D receives transfer trip signal
5. Breaker trips at DER site
6. Status confirmation sent to substation
7. Status info received in substation
Example – Distribution Management Systems

- Data Acquisition and control (DSCADA)
- Tagging
- Permit/Clearance Request Tools
- User Interface with Areas of Responsibility
- Automatic Generation of Schematic Displays
- Intelligent Alarm Processing
- Historical Information System
- Unusual Condition – Off Normal Reports
- Distribution System Model
- Planned Alterations
- Load Models, Load Allocation and Load Estimation
- Topology Processor
- On-Line Distribution Power Flow
- Short Circuit Analysis
- Switch Order Management
- Volt-VAR Optimization
- Fault Location, Isolation, and Service Restoration
- Predictive Fault Location
- Intelligent Bus Failover
- Optimal Network Reconfiguration
- Short Term Load Forecasting
- Voltage Difference Across Open Feeder Tie Points
- Analysis of Peak Demand
- Dispatcher Training Simulator
- Dynamic Equipment Rating
- DMS Control of Protection Settings
- DER/Microgrid Monitoring and Control
- Emergency Load Shedding
  - Integration with External Systems
  - Geographic Information System (GIS)
  - Mobile Workforce Management
  - Automatic Metering Infrastructure (AMI)
  - Outage Management System
  - Energy Management System
  - Corporate Data Warehouse
  - Engineering Analysis Tools

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Distribution Management – Integrated Processes

- Call Center (CIS/CCS/IVR)
- Operations Dispatch
- Trouble and Service (Field Crew Automation)
- Construction (Work Management)
- Control Center (SCADA/DA)
- Management (Executive Information System)
- Marketing (Major Accounts/PBR)
- Public Relations (Media/Local Authorities)
- Planning/Engineering (System Design/Power Quality)

Flowchart:
- Trouble Calls
- Status Inquiry
- Restoration Call Back
- Customer Outage History
- Prioritize Jobs
- Est. Time & Resource
- Outage Closing Info & Reports
- Problem Diagnoses
- Trouble Shoot
- Switching & Repairs
- Heavy Duty Repairs
- Follow-up Repairs
- Network Telemetry
- Resource Allocation
- Switch Order
- Network Control
- Proactive Customer Communication
- Outage Areas
- Resource Planning
- Situation Updates
- O&M Planning And Strategies
- Targeted Market Planning
- Service Improvement Reports
- Optimal Network Design
- Outage and Power Quality Analyses
Communications infrastructure
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Proliferation of Distributed Generation (DG)

- The oil crisis of 1973 triggered a growing interest in energy efficiency and renewable generation, which ultimately lead to the 1978’s Public Utility Regulatory Policies Act (PURPA)
- PURPA allowed industrial facilities and consumers to build and operate distributed generators
- Distributed generation (DG), also known embedded generation, is a term generally used to describe generation connected to distribution feeders and substations. However, small scale generation connected to sub-transmission and transmission lines and close to end users may also be considered DG
- DG can be broadly defined as the utilization of modular small-scale generation technologies interconnected to distribution systems
Proliferation of Distributed Generation (DG)

- DG may be utility or customer-owned, in the latter case the customer may use all its output or sell part or all of it to a local utility.
- Most of the DG being connected to distribution systems is intermittent in nature (photovoltaic, wind), this can lead to significant impacts in the distribution system, e.g., voltage fluctuations.
- PV-DG is rapidly growing, not only in the southwest!
- Utilities along North America must comply with Renewable Portfolio Standards (RPS) requirements (e.g., the goal for the state of California is 33% by 2020), there are incentives in place.
- PV-DG has diverse impacts on distribution system planning and operation (e.g., solar intermittency due to cloud cover can have a significant impact on voltage variations).
- Impacts are not only of steady state but also of dynamic nature (e.g., Transient Overvoltage TOV).
Energy Storage (ES)

- Energy Storage represents a promising solution to this problem
Energy Storage (ES)
Proliferation of Plug-in Electric Vehicles

- Proliferation of PEVs can lead to significant impacts. Impacts depend on system configuration, loading type, and level of penetration.

- Most issues in the near term can be resolved by controlling the charging time – Need to start working now to be able to provide charger control capability

- Large proliferation under *uncontrolled charging* scenarios cause equipment overload, under-voltage and loss increase

- Controlled charging may limit peak demand but leads to coincident charging during off-peak hours: → Affects life cycle

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Source: Quanta Technology
Impact of PV generation and PEVs

Source: Quanta Technology

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PEV, PVs and DES synergies
PEV, PV and DES synergies
Microgrids

- Growing interest in islanded operation of DER (planned islanding of DG units)
- Growing interest in Community Energy Storage (CES) to support Community Energy Systems
- Growing interest in DC distribution (low voltage)
Other areas of interest

- **Zero Net Energy (ZNE):** residential homes and commercial buildings with annual energy consumption equal to zero. This can be accomplished via residential DG. Example of this trend is California’s Big Bold Energy Efficiency Strategies (BBEES)
  

- **Home Automation:** in order to exploit the benefits of the Smart Grid it is necessary to empower customers and optimize utilization of growing number of customer-side components (DERs, PEVs)

- **Interoperability standards:** all IEDs must be able to communicate and exchange data seamlessly. This initiative is being led by NIST
  
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# The Smart Grid of The Future

<table>
<thead>
<tr>
<th>20th Century Grid</th>
<th>21st Century Smart Grid</th>
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<tbody>
<tr>
<td>Electromechanical</td>
<td>Digital</td>
</tr>
<tr>
<td>One-way communications (if any)</td>
<td>Two-way communications</td>
</tr>
<tr>
<td>Built for centralized generation</td>
<td>Integrates distributed generation &amp; renewables and supports EVs or hybrids</td>
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<tr>
<td>Radial topology</td>
<td>Network topology; bidirectional power flow</td>
</tr>
<tr>
<td>Few sensors</td>
<td>Monitors and sensors throughout; High visibility</td>
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<tr>
<td>Manual restoration</td>
<td>Semi-automated restoration &amp; decision-support systems, and, eventually, auto restoration (“self-healing”)</td>
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<tr>
<td>Prone to failures and blackouts</td>
<td>Adaptive protection and islanding</td>
</tr>
<tr>
<td>Scheduled equipment maintenance</td>
<td>Condition-based maintenance</td>
</tr>
<tr>
<td>Limited control over power flows</td>
<td>Pervasive control systems; state estimator</td>
</tr>
<tr>
<td>Not much sustainability concern</td>
<td>Sustainability and Global Warming concern</td>
</tr>
<tr>
<td>Limited price information</td>
<td>Full price information to customers – RTP, CPP, etc.</td>
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1 Modified from the Emerging Smart Grid: Investment And Entrepreneurial Potential in the Electric Power Grid of the Future, Global Environment Fund, October 2005
How will the grid look like?

“Yesterday” – 1890s to 1960s
Role: Generator to Meter; Regulated
Operation: Deterministic + Vertically Planned
Infrastructure: Local and Regional Grids; Mostly Radial;
Grew in Bulk more than Intelligence

“Today” – 1970s to 2015s
Role: Market Trading in addition to Power Delivery
Operation: Increasingly Real-Time & Probabilistic; Deregulated
Infrastructure: Increasingly Networked & Inter-regional;
Automated / Intelligent

“~ 2040 ?
Role: ?
Operation: ?
Infrastructure: ?

Momentum will define much of the look of the 2015 Grid, but events of this decade will help shape much of the look of 2040

Source: Merwin Brown, PIER
Websites of interest

- IEEE Smart Grid
  http://smartgrid.ieee.org/
- IEEE Transportation Electrification
  http://electricvehicle.ieee.org/
- Electricity Storage Association
  http://www.electricitystorage.org
- NREL
  http://www.nrel.gov/
- DOE
  http://energy.gov/
- NIST
  http://www.nist.gov/
Thank You!