Demystifying and De-Jargoning the Smart Grid: What’s Hype, What’s Real, and Where’s the Value?

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Technical Executive
Stanford Lecture Series
January 13th 2010
Electric Power Research Institute
Collaboration.....Technical Expertise.....Thought Leader

- Not for profit, collaborative electricity research organization with more than 450 participants in over 40 countries

- U.S. utilities placed approximately 72% of their R&D investment with EPRI in 2007.

- Independent electricity research in:
  - Generation
  - Environment
  - Power Delivery & Energy Utilization
  - Nuclear

- 1600+ R&D projects annually, ~$300M R&D funding, more than 400 engineers and scientists
EPRI’s IntelliGrid R&D Program
Largest Funded Collaborative R&D Program in Smart Grid

Public Agencies

U.S. Utilities
• 2009 Membership includes over 35 utilities in North America

International Utilities
• Electricite de France
• Polish Power Grid Company
• Iberdrola

Manufacturers
• ABB
• Siemens
• Elster

• Association of State Energy Research and Technology Transfer Institutions
• International Brotherhood of Electrical Workers
• National Association of Regulatory Utility Commissioners
• National Association of Energy Officials
• National Conference of State Legislatures
• National Governors Association
• State Energy Offices and Research Programs

Electricity Industry Technology Providers
Public Sector/Consumers
IntelliGrid: R&D to Develop the Foundation of Smart Grid

- Smart Grid Requirements gathering methodology
- Standards assessment and contribution
- Information model to facilitate systems integration
- Communication technology assessment
- Security Policy for smart grid applications
<table>
<thead>
<tr>
<th>PS 161A</th>
<th>Tech transfer, Technology Watch, Industry Coordination</th>
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<tbody>
<tr>
<td>PS 161B</td>
<td>Infrastructure for Smart Transmission Systems</td>
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<tr>
<td>PS 161C</td>
<td>Infrastructure for Smart Distribution Systems</td>
</tr>
<tr>
<td>PS 161D</td>
<td>Infrastructure for Smart Customer Interface</td>
</tr>
<tr>
<td>PS 161E</td>
<td>Infrastructure Security</td>
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</table>
The CO$_2$ Challenge

**Assumed Economy-wide CO$_2$ Reduction Target**
*(with no international offsets)*

- Historical Emissions
  - 2005 = 5982 mmT CO$_2$
- Remainder of U.S. Economy
- U.S. Electric Sector

- 2030 = 42% below 2005 (3470 mmT CO$_2$)
- 83% Reduction in CO$_2$ emissions below 2005
- 1017 mmT CO$_2$
2009 Prism

U.S. Electric Sector CO₂ Emissions (million metric tons)

- Efficiency
- Renewables
- Nuclear
- Fossil Efficiency
- CCS
- PEV
- Electro-Technologies

EIA 2009 baseline

- 41% below 2005
- 58% below 2005
# 2009 Prism Technology Assumptions

<table>
<thead>
<tr>
<th>Technology</th>
<th>EIA Base Case</th>
<th>EPRI Prism Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>Load Growth ~ +0.95%/yr</td>
<td>8% Additional Consumption Reduction by 2030</td>
</tr>
<tr>
<td>T&amp;D Efficiency</td>
<td>None</td>
<td>20% Reduction in T&amp;D Losses by 2030</td>
</tr>
<tr>
<td>Renewables</td>
<td>60 GWe by 2030</td>
<td>135 GWe by 2030 (15% of generation)</td>
</tr>
<tr>
<td>Nuclear</td>
<td>12.5 GWe New Build by 2030</td>
<td>No Retirements; 10 GWe New Build by 2020; 64 GWe New Build by 2030</td>
</tr>
<tr>
<td>Fossil Efficiency</td>
<td>40% New Coal, 54% New NGCCs by 2030</td>
<td>+3% Efficiency for 75 GWe Existing Fleet 49% New Coal; 70% New NGCCs by 2030</td>
</tr>
<tr>
<td>CCS</td>
<td>None</td>
<td>90% Capture for New Coal + NGCC After 2020</td>
</tr>
</tbody>
</table>

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Transition to Low-Emissions Technologies

- Expanded Advanced Light Water Reactor Deployment
- Enabling Intermittent Renewables via Advanced Transmission Grids
- Enabling Efficiency, PHEVs, DER via the Smart Distribution Grid
- Advanced Coal Plants with CO$_2$ Capture and Storage
2008 EPRI Priority…Analysis to Action

Technology Challenges

1. Enabling energy efficiency with efficient end-use technologies and smart grids
2. Enabling intermittent renewables with advanced transmission and energy storage
3. Deploying advanced light water reactors
4. Deploying CCS by 2020

Demonstration Projects

- Hyper-efficient electric end-use technologies
- Smart grids
- Compressed air energy storage
- PC with partial CCS
- Two alternate capture technologies
- IGCC with partial CCS
- Lower-cost \( \text{O}_2 \) production
Smart Grid
Sensors….Two Way Communications….Intelligence

Acting on this Information Will:

<table>
<thead>
<tr>
<th>Enable active participation by consumers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anticipate &amp; respond to system disturbances (self-heal)</td>
</tr>
<tr>
<td>Operate resiliently against attack and natural disaster</td>
</tr>
<tr>
<td>Optimize asset utilization and operate efficiently</td>
</tr>
</tbody>
</table>
Smart Grid Example Architecture
Smart Grid – Exchanging Information Seamlessly Across the Enterprise

Transmission
Phasor Measurement

Substation
Condition Monitoring

Distribution
Distribution Automation

Consumer
“Prices to Devices” (Demand Response)

Communication Enabled Power Infrastructure
Developing the Common Information Model (CIM) for Distribution Applications

IEC 61970/61968 Common Information Model (CIM) Enterprise Application Integration

CIS
EMS
OMS
Distribution Automation

"Middleware" "Integration Bus"

AM/FM/GIS
Customer Communications
Work Management
Meter Data Management

ANSI/IEC Metering "Field Operations"

Field Data Collection
The Intelligrid Program – Laying the Foundation

EPRI’s IntelliGrid Methodology is Focused on Helping Our Members Build the Right Foundation

Smart Grid Foundation

- Security
- Information Management
- Communications
- Interoperability
- Systems Engineering Methodology
Vision for Distribution Management System integration with Smart Grid

- Asset Management
- GIS
- Distribution Model
- Planning/Forecasting
- AMI/MDMS/CIS
- Outage Data
- OMS
- DMS
- SCADA
- DA
- VVC
- Efficiency
- DG
- DSM, PHEV
Architecture Identifies Information Exchange Requirements
NIST Phase 2 and Phase 3 Plan

PHASE 1
Recognize a set of initial existing consensus standards and develop a roadmap to fill gaps

EPRI Report to NIST

PHASE 2
Establish public/private Standards Panel to provide ongoing recommendations for new/revised standards to be recognized by NIST

PHASE 3
Conformity Framework (including Testing and Certification)

March 2009  September 2010
## Standard Gap Assessment - Priority Action Plans

<table>
<thead>
<tr>
<th>#</th>
<th>Priority Action Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IP for the Smart Grid</td>
</tr>
<tr>
<td>2</td>
<td>Wireless Communications for the Smart Grid</td>
</tr>
<tr>
<td>3</td>
<td><strong>Common Pricing Model</strong></td>
</tr>
<tr>
<td>4</td>
<td>Common Scheduling Mechanism</td>
</tr>
<tr>
<td>5</td>
<td>Standard Meter Data Profiles</td>
</tr>
<tr>
<td>6</td>
<td>Common Semantic Model for Meter Data Tables</td>
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<tr>
<td>7</td>
<td>Electric Storage Interconnection Guidelines</td>
</tr>
<tr>
<td>8</td>
<td><strong>CIM for Distribution Grid Management</strong></td>
</tr>
<tr>
<td>9</td>
<td>Standard Demand Response Signals</td>
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<tr>
<td>10</td>
<td>Standard Energy Usage Information</td>
</tr>
<tr>
<td>11</td>
<td>Common Object Models for Electric Transportation</td>
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<tr>
<td>12</td>
<td><strong>IEC 61850 Objects/DNP3 Mapping</strong></td>
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<tr>
<td>13</td>
<td>Time Synchronization, IEC 61850 Objects/IEEE C37.118 Harmonization</td>
</tr>
<tr>
<td>14</td>
<td>Transmission and Distribution Power Systems Model Mapping</td>
</tr>
</tbody>
</table>

**Action Plan Covers Transmission, Distribution, and Consumer Domain**
EPRI Smart Grid Demonstrations

• Deploying the Virtual Power Plant
• Demonstrate Integration and Interoperability
• Leverage information & Communication Technologies

• Integration of Multiple Types of Distributed Energy Resources (DER):
  - Distributed Generation
  - Renewable Generation
  - Storage
  - Demand Response

• Multiple Levels of Integration - Interoperability
Smart Grid Demonstration - 19 Collaborators
(Uilities giving permission to list their names. 7/23/2009)

Wisconsin Public Service
Ameren
KCP&L
Southwest Power Pool
Salt River Project
PNM Resources
TVA
Entergy
Central Hudson Gas & Electric
ESB Networks
Con Edison
Electricité de France
FirstEnergy / JCP&L
PSE&G
AEP
Duke
Southern

- Collaborator
- Collaborator / Host-Site

6 Host-Sites Selected, 2-5 more to be selected by August 2010
4 Pillars of Cyber Security

• Confidentiality (e.g. Encryption, VPN, Authentication, etc.)

• Integrity (Digital Signatures, Check Sum, etc.)

• Availability (e.g. % uptime of critical applications)

• Reliability (e.g. Probability of successful transmission)
Securing Smart Grid Infrastructure (Best Practices)

Requires Comprehensive Approach

- Hardening Issues (e.g. Stateful Inspection, Access Control, Anti-virus)
- Managing Residual Risk (e.g. Intrusion Detection & Prevention)
- Process Control (e.g. Role based authorization, biometrics etc.)
- People Training (e.g. Counter measures to social conditioning)

Need Layered Defense Model to thwart potential hacker at multiple levels

Establish use case based security requirements at Smart Grid Interfaces

Adopt open security standards that support the requirements
Smart Grids and Local Energy Networks
Smart Grids and Local Energy Networks

- Utility Communications
- Dynamic Systems Control
- Data Management
- Distribution Operations
- Advanced Metering
- Control Interface
- Renewable PV
- Consumer Portal & Building EMS
- Distributed Generation & Storage
- Plug-In Hybrids
- Efficient Building Systems
- Internet
- Smart End-Use Devices
- Smart Grids and Local Energy Networks

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General HAN Communication Network Architecture

Utility Owned

Utility Data Acquisition Point

2-Way

Wireless and/or Power Line Carrier

2-Way

Consumer Owned

Third-Party Access Provider
Modem/DSL/Cable/Satellite
Wide Area Network

2-Way

Protocol Specific Interface

Advanced Meter

Energy Management System

2-Way

Third-Party Access Provider
One-Way Wireless Communication Network

1-Way

Thermostat

Expansion Port

2-Way

Protocol Interface

Home Area Network Protocols
Zigbee
Insteon
Z-wave
HomePlug (etc.)

2-Way

Pool Pump, Water Heater, etc.

PV, Wind Turbine, etc.

Plug-In EV

Courtesy CEC/PIER April 2007
Home “Automation” Standards...

1985

- X-10™
- CEBus©
- Lonworks™
- Smarthouse
- Firewire
- CAL/HPnP
- Home RF
- Bluetooth
- SWAP
- WLIF
- Home PNA
- Home API

“Digital Convergence”

2007

- HES
- SNAP
- HOP
- UPnP
- ATM RBB
- Jini/Java
- HAVi
- OSGi
- IRDA
- VESA
- WLIF
- SOAP
- HomePlug
- ZigBee
- UWB
- AHAM CHA
- Ethernet
- IPvX
- WSDL
- UDDI
- XML
- EIB
- Konnex
- BACnet
- HomeGate

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7-Layer Communication Protocol Architecture

<table>
<thead>
<tr>
<th>OSI Model</th>
<th>TCP/IP Model</th>
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<tr>
<td>7</td>
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<tr>
<td>Application</td>
<td>FTP</td>
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<tr>
<td>6</td>
<td>TE</td>
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<td>Presentation</td>
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<td>Session</td>
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<tr>
<td>Physical</td>
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</table>

Integrated OSI Layers 5-7
TCP
IP
Ethernet
SONET
ICMP
### Home Area Network Communication Protocol Stack View

<table>
<thead>
<tr>
<th>OSI Model</th>
<th>HomePlug</th>
<th>Insteon</th>
<th>Z-wave</th>
<th>Zigbee</th>
<th>TCP/IP Model</th>
</tr>
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<tr>
<td>7</td>
<td>Application</td>
<td>7</td>
<td>Integrated OSI Layers 1-7</td>
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<td>6</td>
<td>Presentation</td>
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<td>TCP</td>
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<td>Physical</td>
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<td>1</td>
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</tbody>
</table>

- **Z-wave & Insteon** are the two major players in this market (70% of current market)

- **HomePlug** and **ZigBee** are gaining market share in HAN automation & control through utility-based DR program offering
What are the features of the ZigBee protocol?

- Low power low bandwidth wireless protocol
- Operates at 2.4 GHz ISM Band in the US
- Uses an RF Mesh topology
- Publicly available spec
- Physical and Data Link Layer is governed by the IEEE 802.15.4 standard
- Stack in Layers 3-7 has not been approved by any Standards Development Organization (SDO)
- Pro Stack has the Smart Energy Application Profile at the Application Layer
What are the features of the HomePlug protocol?

- A power line carrier (PLC) based communication protocol
- Primarily defined at Layers 1-2 of the protocol stack
- Can use TCP/IP for Layers 3-7 of the protocol stack

Specification defines 3 types of transport:

- AV (up to 200 Mb/s)
- 1.0 (14 Mb/s half duplex)
- Command & Control (7.5 Kb/s at Layer 1)
Current HAN Automation and Control Protocol Landscape for Energy Management

- Insteon
- HomePlug
- Z-Wave
- ZigBee
- Wi-Fi

- Air Conditioner
- Pool Pump
- Water Heater
Alternative Home DR Program Through Internet Gateway

Smart Energy Application Profile 2.0

Zigbee, HomePlug, Wi Fi

Air Conditioner, Pool Pump, Water Heater, Refrigerator
Computer/Laptop, Flat Screen TV, Washer/Dryer
Plug-in Hybrid Electric Vehicle, Wind Turbine, Solar Panels
Future HAN Automation & Control Protocol Landscape for Utility Applications

Smart Energy Application Profile 2.0

- Zigbee
- HomePlug
- Wi-Fi

Air Conditioner  Pool Pump  Water Heater  Refrigerator
Computer/Laptop  Flat Screen TV  Washer/Dryer
Plug-in Hybrid Electric Vehicle  Wind Turbine  Solar Panels
Smart Grid Enabling Demand Response Through Demand Response (DR) Ready Appliances

Media Agnostic

Intelligent Communicating Appliances

Utility Smart Grid

Wireless

Fiber Optic

Copper Wire

Powerline Carrier

Designation & Certification to Encourage Manufacturers to Develop DR-Ready Products

Barriers: Standards for DR Interface & Market Transformation to Embed DR Interface
Technical Challenge: Develop standards for exchanging information with smart appliances

Utility Smart Grid

Media Agnostic

Intelligent Communicating Appliances

Standard data packet for two-way communications and data exchange
Future Direction of HAN Interoperability

• HomePlug and Zigbee are working together to develop a Smart Energy Application Profile 2.0 that will work over both communication protocols (Tentative Release Date – Mid 2010)

• HomePlug+Zigbee Joint Alliance includes 6-8 major utilities, product vendors and technical experts from the industry that are helping to accelerate the development and acceptance of this standard in HAN automation and control market (To be included as part of IEC CIM)

• Should Wi-Fi Alliance join the ZigBee+HomePlug Joint Alliance’s efforts, a truly interoperable Application Layer HAN profile could be established for enabling Demand Response & Energy Efficiency Programs in the residential sector
It Takes Time to Develop and Adopt Standards.....
Example of Utility Energy Management System (EMS) Standard

- Initial Design to IEC
- World Experts - Utilities Begin Design
- 1994

- Initial Implementations
- Review – Revise by Standards Body
- 1996

- Interoperability Test to Validate Design
- 1998

- 8 Years for Original Formal Approval
- 2000

- 2002

EPRI’s IntelliGrid Research Results Can Significantly Accelerate the Development of Standards for Exchanging Information with DR Ready Appliances
Home Area Network Supplemental Project
2010
Problem Definition

Current Home Area Network configurations rely on technologies that are not well understood in the residential setting. Utilities have concerns about the attenuation, propagation, and penetration of RF and BPL technologies into the home. Simple to use, easily installed, and very inexpensive devices will have to operate with near-zero service calls to justify their costs.

This project will document signal strength, reliability, and performance of HAN equipment in a substantial number of utility employee homes.
Project Description

- Document performance in the home of:
  - ZigBee
  - Homeplug (CC, 1.0, AV)
  - ERT (Itron)

- 10-50 employee homes per utility
- Residential floor plan – varying age, construction, foliage
- HAN-enabled meter

- Floor Plan Survey (1/2 day)
  - each room
  - each major load in the home

- Reliability (4 days)
  - Continuous operation – LQI, Data Rate, PER
Candidate Test Tools

- HAN enabled meter (ZigBee, Homeplug, ERT)
- Potential end point test device (People Power Company OSHAN, Daintree, Ember, MMB, Tendril, RTA, PlugSmart, Itron, Aztek, Comverge)
- Laptop/Tablet + applications
  - Installation
  - Floor Plan Test data collection
  - Reliability Test data collection
- Data analysis application (at EPRI)

Collected Data
- Location on Floor Plan
- LQI/RSSI/dBm (signal strength)
- Packet Error Rate
- Throughput - bps
Proposed Project Responsibilities

EPRI

- Project management
- Develop site survey
- Provide Test design, test scripts
- Hardware specification, contracting
- Train utility testers on ZB & HP Performance SW
- Analysis and report writing

Utilities

- Fund the supplemental ($60K per utility)
- Current Funders (AEP, Consumers, TVA)
- Populate the project advisory board
- Arrange Vendor NDAs
- Test design review and approval
- Solicit employee home volunteers
- Collect data and return to EPRI
PS 161D
Project Set Plan for 2010 & Beyond
Evaluation of Communications Technologies for Demand Response & DER Integration

• Types of Technologies to be Evaluated:
  • AMI/HAN & Broadband Based Gateways
  • Renewable Sources for Homes (PV & Solar Thermal)
  • Energy Storage (Electric & Thermal)
  • Plug-In Electric Vehicles

• Types of Activities
  • RF & PLC Signal Propagation Studies in AMI & HAN
  • Testing & Evaluation of Communication Interfaces
  • Testing Integration Capability with Smart Grid
  • Demonstration of Demand Response Capability
Smart Grid Communications Architecture for Demand Response & DER Integration

• Development of a Standards Based 7-Layer
• Communication Architecture for Smart Grids Including (Continuation of NIST Interoperability Framework Research):

  – Building Automation Systems
  – Distribution Systems
  – Distributed Energy Resources
  – Plug-In Electric Vehicles
  – Advanced Meters
  – Metering Data Management System
Life Cycle Management of Technologies for Demand Response & DER Integration

• Full Product Life Cycle Support Including:
• Use Case Analysis
• Product Requirements Document Preparation
• Vendor Product Testing, Evaluation & Certification
• Product Selection & Procurement
• Implementation Guidance & Best Practices
• Configuration & Functional Testing
• Operations & Management (FCAPS)
• Data Collection, Transmission, Storage, & Usage
• End of Product Life Preparation
• Transition to Next Generation Technologies
2010 Projects in 161D

• 161.006 – 700 MHz, 900 MHz and 2.4 GHz RF Propagation Characteristics in AMI Mesh & Tower Based Networks in Rural & Urban Settings

• 161.007 – Graphical Representation of End-to-end 7-Layer AMI & HAN Communication Architecture with Applicable Interoperability Standards Mapping

• 161.008 – Developing Standardized Performance Metrics for HomePlug, IEEE 802.15.4 and Wi-Fi
2010 Projects in 161E

• 161.009 – Control Center Cyber Security Best Practices

• 161.007 – Sub-station Best Practices

• 161.008 – Distribution System Security Requirements

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Together…Shaping the Future of Electricity