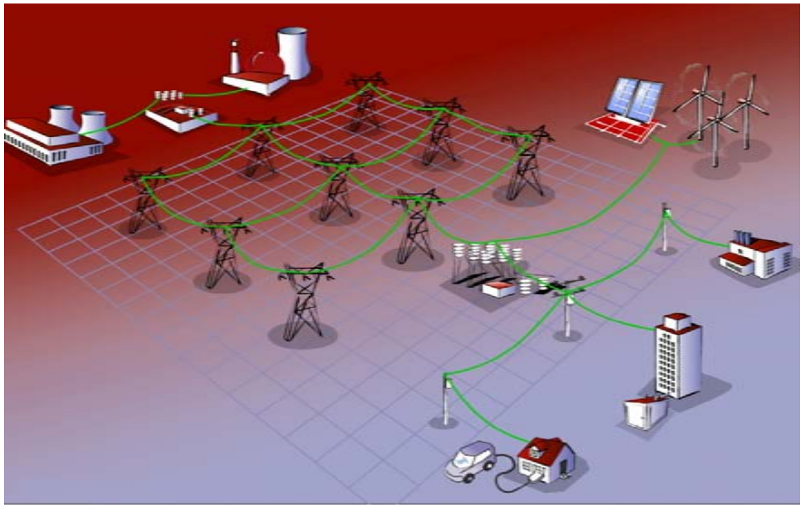
NATIONAL ENERGY TECHNOLOGY LABORATORY



Results from DOE's ARRA Smart Grid Program

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IEEE IAS/PES Pittsburgh Section

October 23, 2013

U.S. DEPARTMENT OF ENERGY

Topics

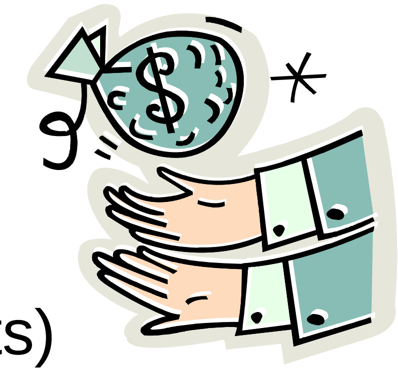
- OE ARRA Smart Grid Program
- OE ARRA Smart Grid Progress
- Results and Case Studies
- Life After ARRA Smart Grid

DOE OE ARRA
Smart Grid Program

Smart Grid ARRA Activities

American Recovery and Reinvestment Act ($4.5B)

- Smart Grid Investment Grants (99 projects)
  - $3.4 billion Federal; $4.7 billion private sector
  - > 800 PMUs covering almost 100% of transmission
  - ~ 8000 distribution automation circuits
  - > 15 million smart meters



- Smart Grid Demonstration Projects (32 projects)
  - $685 million Federal; $1 billion private sector
  - 16 storage projects
  - 16 regional demonstrations

Value Proposition

Cost to Modernize

- $338-$476B over 20 years
  - $ 82-90B for transmission
  - $232-$339B for distribution
  - $24-46B for consumer
- $17-24B per year ***EPRI, 2011***

Smart Grid Field Projects

ARRA investments

SGIG: $8.1B ($3.4B Federal)

SGDP: $1.7B (0.7B Federal)

Total $9.8B ($4.1B Federal)

- Other cost estimate: Brattle ~$880B

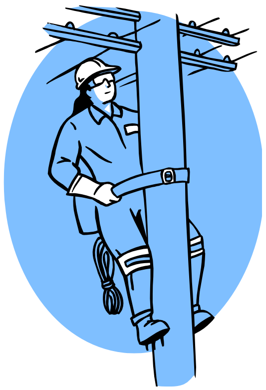
EPRI Report: http://www.smartgridinformation.info/pdf/3272_doc_1.pdf

Smart Grid investment from ARRA field projects is 1 to 3% of investment required to build a national smart grid

Smart Grid ARRA Activities (continued)

Additional ARRA Smart Grid Activities

- Interoperability Framework by NIST ($12M)
- Transmission Analysis and Planning ($80M)
- State Electricity Regulator Assistance ($49M)
- State Planning for Smart Grid Resiliency ($52M)
- Workforce Development ($100M)



Technology Deployment

SGIG/SGDP Areas of Smart Grid Technology Deployment				
Customer Systems	**Advance Metering Infrastructure**	**Electric Distribution Systems**	**Electric Transmission Systems**	**Equipment Manufacturing**
				
• Displays • Internet portals • Direct load controls • Programmable thermostats • EV Chargers	• Smart meters • Data management • Back office integration	• Auto switches • Automated capacitors • Auto voltage regulators • Equipment monitoring • Energy Storage	• Wide area monitoring • Synchrophasor Technology • Phasor data concentrators • Dynamic line rating • Energy Storage	• Energy devices • Software • Appliances

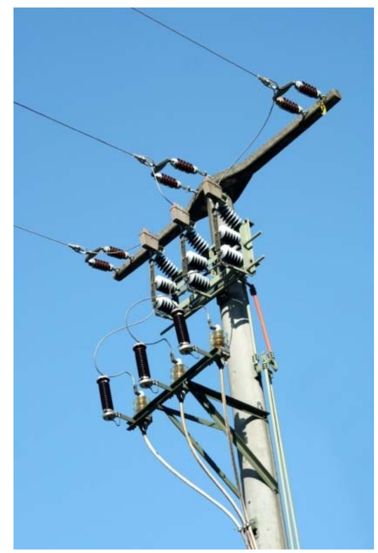
Current Deployment of Smart Grid Applications

Conservation voltage reduction
Improving power factors
Distribution and substation automation
- Feeder reconfiguration
- Voltage and frequency control
- Volt/VAR balance
- Automated load balancing

Demand response & consumer behavior
Outage management
Remote services (e.g., reading, connection)
Condition-based maintenance
Transmission real-time situational awareness

Current Deployment of Smart Grid Technologies

- Smart meters
- Two-way communications (i.e., AMI)
- Automated capacitors
- Smart sensors, switches, reclosers
- Phasor measurement units
- Cyber security
- Weather forecasting
- Equipment health monitors
- Smart appliances
- Home energy displays and networks

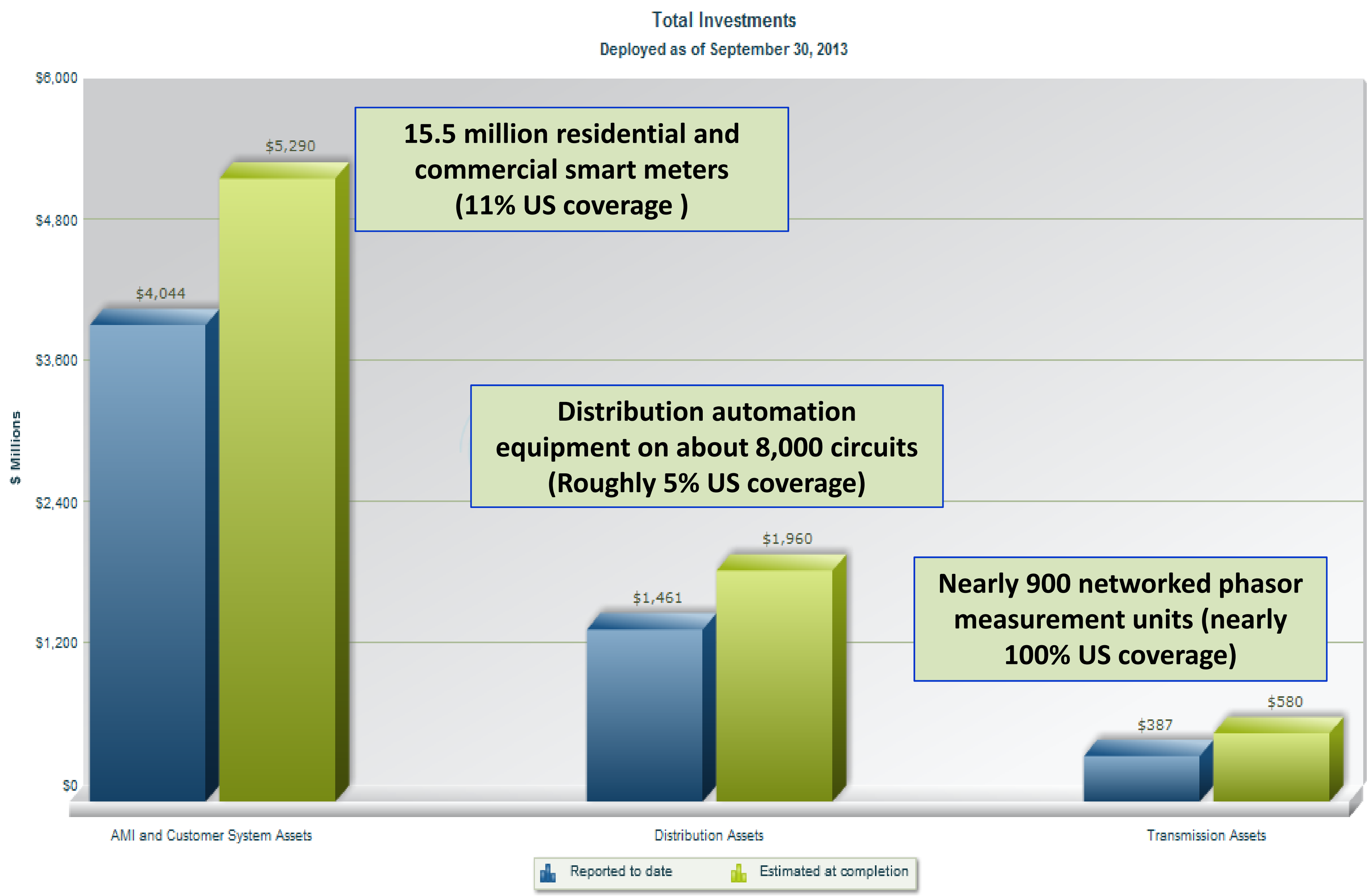


Applications and Benefits Matrix

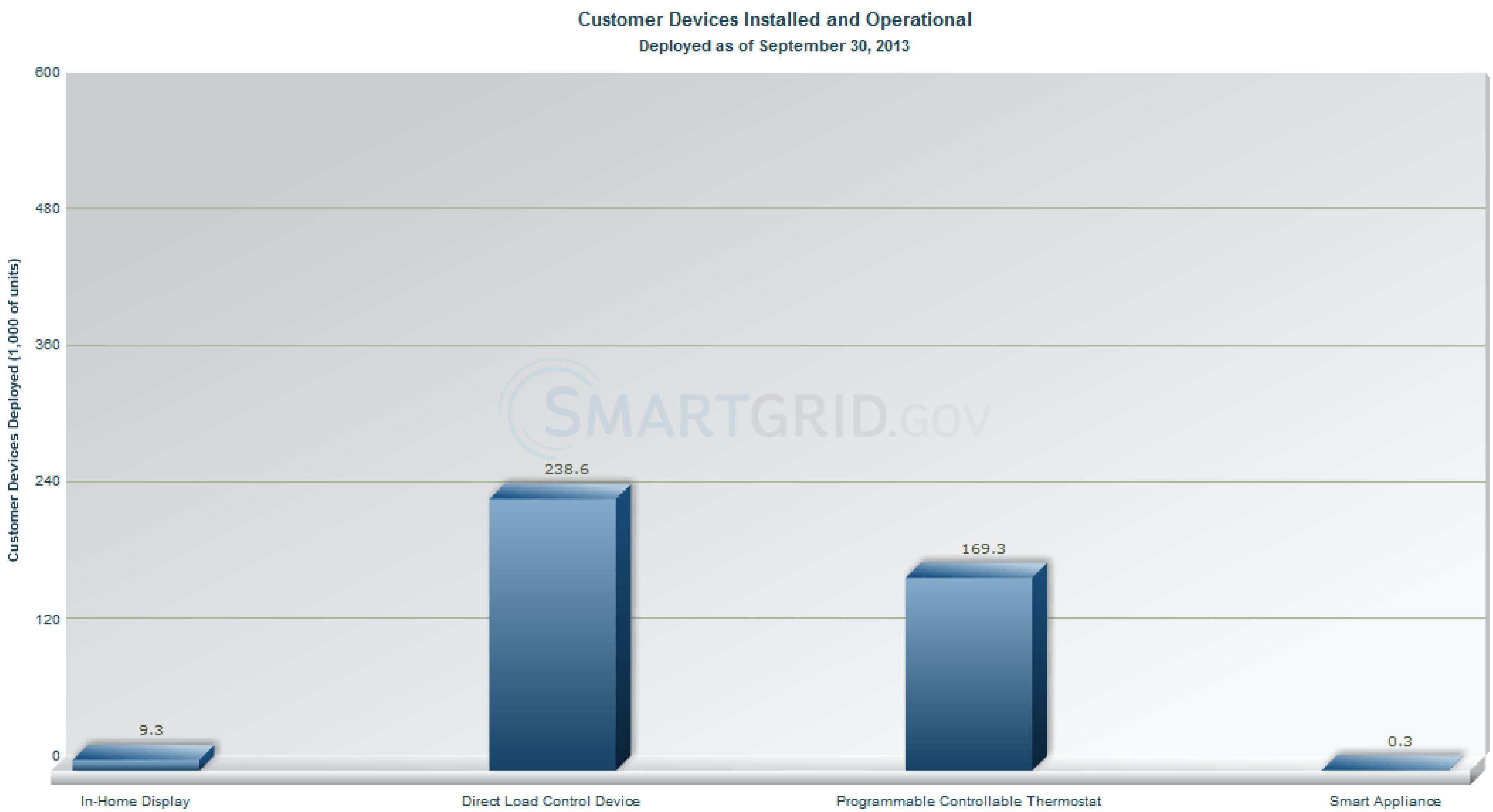
Benefits	Smart Grid Technology Applications					
	Consumer-Based Demand Management Programs (AMI-Enabled)	Advanced Metering Infrastructure (AMI) Applied to Operations	Fault Location, Isolation and Service Restoration	Equipment Health Monitoring	Improved Volt/VAR Management	Synchrophasor Technology Applications
	• Time-based pricing • Customer devices (information and control systems) • Direct load control (does not require AMI)	• Meter services • Outage management • Volt-VAR management • Tamper detection • Back-Office systems support (e.g., billing and customer service)	• Automated feeder switching • Fault location • AMI and outage management	• Condition-based maintenance • Stress reduction on equipment	• Peak demand reduction • Conservation Voltage Reduction • Reactive power compensation	• Real-time and off-line applications
Capital expenditure reduction – enhanced utilization of G,T & D assets	✓			✓	✓	✓
Energy use reduction	✓	✓	✓		✓	✓
Reliability improvements		✓	✓	✓		✓
O&M cost savings		✓	✓	✓		
Reduced electricity costs to consumers	✓				✓	
Lower pollutant emissions	✓	✓	✓		✓	✓
Enhanced system flexibility – to meet resiliency needs and accommodate all generation and demand resources	✓	✓	✓	✓	✓	✓

ARRA Smart Grid Progress

SGIG Deployment Status



Customer Devices in SGIG Projects



Results and Case Studies

Recent DOE SGIG Reports

- ***Economic Impact of Smart Grid Investments***
  April 2013
- ***2012 Progress Report***
  July 2012
- ***Impact Reports***
  December 2012
  - ✓ *O&M Savings from AMI*
  - ✓ *Demand Reductions from AMI*
  - ✓ *Volt/VAR Optimization*
  - ✓ *Reliability Improvements from DA*

As of May 2013

U.S. DEPARTMENT OF ENERGY
Electricity Delivery & Energy Reliability
American Recovery and Reinvestment Act of 2009
Economic Impact of Recovery Act Investments in the Smart Grid
Analysis of Vendor Payments through the Smart Grid Investment Grant and Smart Grid Demonstration Projects as of March 2012
Smart Grid Investment Grant Program
April 2013
SMARTGRID.GOV

U.S. DEPARTMENT OF ENERGY
Electricity Delivery & Energy Reliability
American Recovery and Reinvestment Act of 2009
Smart Grid Investment Grant Program
Progress Report
July 2012
SMARTGRID.GOV

U.S. DEPARTMENT OF ENERGY
Electricity Delivery & Energy Reliability
American Recovery and Reinvestment Act of 2009
Operations and Maintenance Savings from Advanced Metering Infrastructure – Initial Results
Smart Grid Investment Grant Program
December 2012

U.S. DEPARTMENT OF ENERGY
Electricity Delivery & Energy Reliability
American Recovery and Reinvestment Act of 2009
Demand Reductions from the Application of Advanced Metering Infrastructure, Pricing Programs, and Customer-Based Systems – Initial Results
Smart Grid Investment Grant Program
December 2012

U.S. DEPARTMENT OF ENERGY
Electricity Delivery & Energy Reliability
American Recovery and Reinvestment Act of 2009
Application of Automated Controls for Voltage and Reactive Power Management – Initial Results
Smart Grid Investment Grant Program
December 2012
SMARTGRID.GOV

U.S. DEPARTMENT OF ENERGY
Electricity Delivery & Energy Reliability
American Recovery and Reinvestment Act of 2009
Reliability Improvements from the Application of Distribution Automation Technologies – Initial Results
Smart Grid Investment Grant Program
December 2012
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Selected examples from SGIG projects reporting initial results

Project Elements	OG&E 770,000 customers	MMLD 11,000 customers	SVE 18,000 customers
Customers Tested	6,000 residential	500 residential	600 mostly residential
Time-Based Rate(s)	TOU and VPP, w/CPP	CPP	CPP
Customer Systems	IHDs, PCTs, and Web Portals	Web Portals	Web Portals
Peak Demand Reduction	Up to 30% 1.3 kW/customer (1.8 kW/customer w/CPP)	37% 0.74 kW/customer	Up to 25% 0.85 kW/customer
Outcome	Deferral of 210 MW of peak demand by 2014 with 20% participation	Lowers total purchase of peak electricity	Lowers total purchase of peak electricity
Customer Acceptance	Positive experience, many reduced electricity bills	Positive experience, but did not use the web portals often	Interested in continued participation, many reduced electricity bills

AMI Improvements in Operational Efficiencies

Results from 15 projects due to automation of metering service tasks and reductions in labor hours and truck rolls

Smart Meter Capabilities	O&M Savings	% Reduction
• Remote meter reading • Remote service connections/disconnections	Meter Operations Cost	13-77
	Vehicle Miles	12-59

Future SGIG examples to provide information on other benefits

Smart Meter Capabilities	Expected Benefits
• Tamper detection and notification	Enables potential recovery of ~1% of revenues that may be lost from meter tampering
• Outage detection and notification	Enables faster restoration (e.g., PECO avoided 6,000 truck rolls following Superstorm Sandy and accelerated restoration by 2-3 days)
• Voltage and power quality monitoring	Enables more effective management of voltages for conservation voltage reductions and other VVO applications

Reliability Improvements from Automated Feeder Switching

Selected examples from SGIG projects reporting initial results

4 Projects involving 1,250 feeders

April 1, 2011 through March 31, 2012

Index	Description	Weighted Average (Range)
SAIFI	**System Average Interruption Frequency Index (outages)**	**-22 %** (-11% to -49%)
MAIFI	**Momentary Average Interruption Frequency Index (interruptions)**	**-22 %** (-13% to -35%)
SAIDI	**System Average Interruption Duration Index (minutes)**	**-18 %** (+4% to -56%)
CAIDI	**Customer Average Interruption Duration Index (minutes)**	**+8 %** (+29% to -15%)

Weighted average based on numbers of feeders

Value of Service from Improvements in Reliability

Selected example from an SGIG project reporting initial results

1 project involving 230 automated feeder switches on 75 circuits in an urban area

From Apr 1 – Sep 30 2011

SAIDI improved 24%; average outage duration decreased from 72.3 to 54.6 minutes (17.7 minutes)

Estimated Average Customer Interruption Costs US 2008$ by Customer Type and Duration						
Customer Type	**Interruption Cost Summer Weekday**	**Interruption Duration**				
		Momentary	**30 mins**	**1 hr**	**4 hr**	**8 hr**
Large C&I	**Cost Per Average kWh**	**$173**	**$38**	**$25**	**$18**	**$14**
Small C&I	**Cost Per Average kWh**	**$2,401**	**$556**	**$373**	**$307**	**$272**
Residential	**Cost Per Average kWh**	**$21.6**	**$4.4**	**$2.6**	**$1.3**	**$0.9**

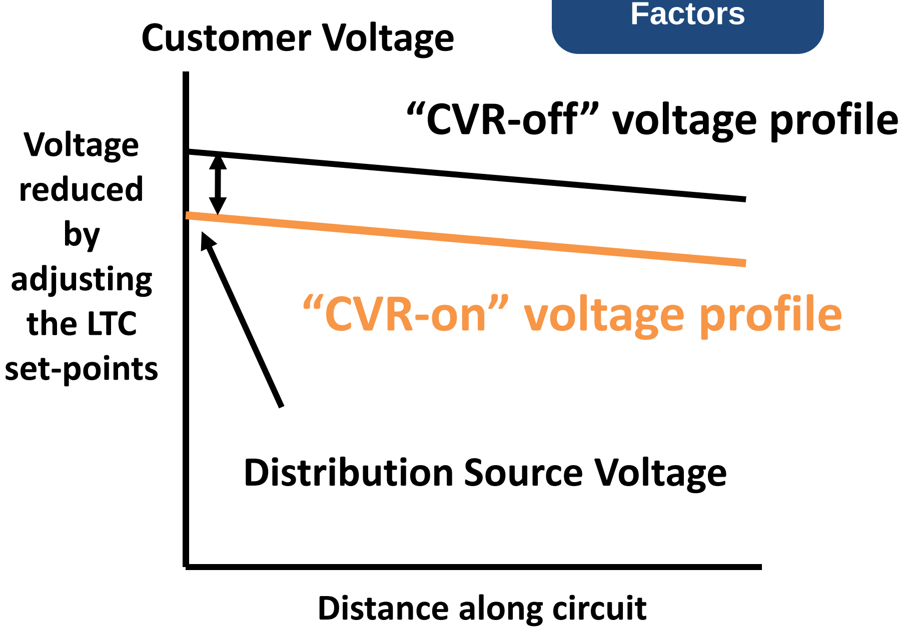
Sullivan J, Michael, 2009 *Estimated Value of Service Reliability for Electric Utility Customers in the US*, xxi

Estimated monetary value of this improvement in reliability based on value-of-service data is $21 million

Applying Volt / VAR Optimization to Improve Energy Efficency

Conservation voltage reduction (CVR) reduces customer voltages along a distribution feeder for lowering peak demands and overall energy consumption

Energy and Capacity CVR Factors



Example Using SGIG Project Data

Results averaged across 11 circuits	% Reduction	Potential savings for a 7 MW peak circuit with 53% load factor	
Customer Energy Reduction	2.9%	943 MWh/year	$75,440 (at $.08/kWh)
Peak Demand Reduction	3%	210 kW	Defer construction of peaking plants

Case Study

Investor-Owned Utility

Florida Power and Light (FPL)

Smart Grid Solutions Strengthen Electric Reliability and Customer Services in Florida

Key Activities

- 3 million smart meters being installed with pilot programs testing customer systems and time-based rate programs.
- Thousands of substation devices for automating switches, capacitors, transformers, and regulators and equipment health monitors at substations.
- 45 phasor measurement units and supporting transmission line monitors.

Aims and Strategies

- Improve reliability by monitoring key transmission and distribution equipment for preventative maintenance and avoidance of outages.
- Make operational efficiency improvements by reducing truck rolls for service calls by automating meter functions.
- Engaging customers through information exchange via web portals and pilot programs with customer systems and time-based rates

Results and Benefits

- In January, 2012, monitor detected an out-of-tolerance high voltage bushing and customers served by this transformer temporarily switched to another one. Meanwhile, the faulty bushing replaced, preventing an outage that would have affected several thousand customers.
- In September, 2011, an alarm signaled a potential problem with a degraded phase on a capacitance voltage transformer. Field engineers located the damaged transformer, removed the affected transmission line section from service, and replaced the defective device thus preventing an extended outage and that could have affected several thousand customers.

One of SGIG's largest and most comprehensive projects

Smart transformers report on health and status to FPL control centers

Facts & Figures

Total Project Budget:
$578,000,000

Federal Share:
$ 200,000,000

FPL Facts:
4.5 million customers
70,000 miles of power lines
16 power plants

Consolidated Edison Company of New York, Inc.

Bright Lights, Big City: A Smarter Grid in New York

What Con Edison is doing

- ***Distribution system automation/upgrade of 850 of 2,513 circuits:***
- ***Two-way communication between distributed generation sites and control centers***

Why Con Edison is doing it

- ***To reduce frequency and duration of costly outages***
  - ***Goal: 40%-50% reduction in large-scale outages in top 10 critical locations***
- ***To improve power quality***

The tangible results so far (June 2013)

Tripled underground feeder sectionalizing capacity
Reduced risk of outages in underground distribution networks by over 30%

Expanded automated overhead switches by 35%
Realized 25% improvement in SAIFI resulting in avoiding 17,000 outages

Distribution capacitors lowered T&D losses and caused $500K in energy savings
Increased the T&D system capacity by 25 MW deferring $5M of capital investments

More than doubled the underground distribution system monitoring capability
installed 8000 sensors resulting in $1 million annual savings through CBM

During Hurricane Sandy, avoided over 100 truck rolls through automated operation of overhead circuits to minimize customer impact.

Service Area

Smart Switch – Key Component to ConEdison's Intelligent Underground System

M2M Communications

Irrigation Load Management is Saving Money and Water in California

Key Activities

- *M2M Communications has designed, and is currently installing, load control and monitoring devices on irrigation pumps in the Central Valley of California. M2M enrolls customers in Peak Energy Agriculture Rewards (PEAR), a program M2M created with California utilities. M2M plans to install control equipment on 1,000 irrigation pumps, representing about 180 MW of interruptible load.*

Aims and Strategies

- *M2M's smart grid-compatible, web-to-wireless system provides farmers with the ability to monitor electricity usage and water consumption, as well as soil moisture content and temperature.*
- *Via a web portal, farmers and power companies can remotely start up or shut off pumps, saving time, manpower, and money.*
- *Farmers earn cash incentives and avoid peak demand charges.*

Results and Benefits

- *DOE ARRA funds greatly contributed to M2M's final R&D push to get the control devices to market.*
- *300 pumps have been deployed so far, representing about 60 MW of interruptible load. PG&E called four critical peak pricing events in 2011; PEAR program participation reduced summer peak demand by an average of 18 MW per event.*

Reducing Peak Electric Demand and Benefiting Farmers and Consumers

An irrigation pump connected to and controlled by M2M's web-to-wireless control device

Facts & Figures

Total Project Budget: *$4,342,340*

Federal Share: *$2,171,170*

Devices installed: *300*

Total summer peak demand reduction in 2011: *72 MW*

Case Study

Electric Cooperative

eEnergy Vermont

A State-Wide Strategy for Smart Grid Development

Key Activities

- Smart metering roll-out for outage management and time-based rates for demand response.
- Distribution system automation including switches, reclosers, SCADA, and communications backbone systems.
- Consumer behavior studies by Vermont Electric Cooperative (VEC)and Central Vermont Public Service to assess customer acceptance, response, and retention.

Aims and Strategies

- A collaborative effort involving all of the state's electric distribution companies to modernize Vermont's electric grid and foster economic growth as part of the state's "eState Initiative" with telecommunications and health care.

Results and Benefits

- VEC's outage management system has improved SAIFI by 50% and CAIDI by 40% since installed in 2008.
- VEC's smart metering roll-out and outage management system has a 5 year payback period from operational saving alone.
- VEC received POWER Magazine's first "Smart Grid Award" in August 2011 for its pioneering efforts in outage management.
- Restoration of the grid from Tropical storm Irene occurred quicker and with greater customer awareness of repair schedules due to smart meters, web portals, and more effective outage management.

Utilities working together to modernize the grid.

Vermont Electric Cooperative's Smart Grid Operations Center

Facts & Figures

Total Project Budget: $137,857,302

Federal Share: $69,928,650

Distribution Automation: 47 circuits and substations

Smart meters: 311,380

Time-Based Rates: 1,500 customers targeted

Case Study

Municipal Power

Electric Power Board (EPB) of Chattanooga

Improved System Restoration in Tennessee and Georgia

What EPB is doing

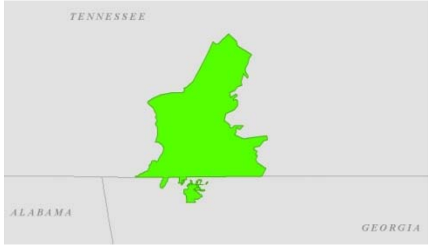
- **Distribution system upgrades**
  - 1,500 smart switches across the system
  - Sensor equipment
  - Enhanced SCADA system
- **Customer-sited equipment and systems**
  - Smart meters
  - In-home displays, smart thermostats, direct load control devices, and other energy management systems
  - Web portal
  - Two-way communications system

Why EPB is doing it

- To increase electric service reliability
- To restore service more quickly in case of outages
- To reduce costs from distribution line losses, equipment failure, truck rolls, and repair crews

The tangible results so far (June 2011)

- Installed smart switches allowed EPB to restore power to all but 1,800 of 61,000 affected customers in less than 36 hours after April 2011 tornado outbreak



Service Area

Smart Switch

April 2011 Storm Damage

Case Study

Transmission Interconnect

Western Electricity Coordinating Council

Modernizing the transmission system in the Western Interconnection

What WECC is doing

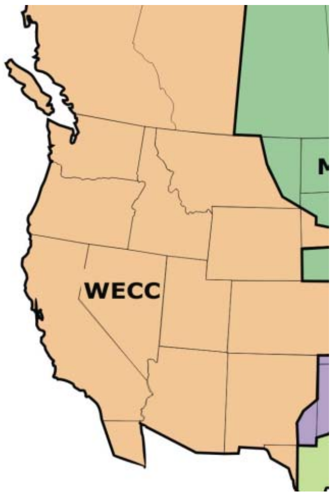
- ***Installing more than 300 phasor measurement units (PMUs) and 60 phasor data concentrators (PDCs) across Western Interconnection***
- ***Expanding 2 data centers***
- ***Installing communications infrastructure and software applications***

Why WECC is doing it

- ***Grid operators need better tools for managing power flows over wide geographic areas in order to:***
  - ***Increase reliability and system performance***
  - ***Avoid large-scale regional outages in the West***
  - ***Enable greater use of renewable resources, such as wind, hydro, and solar***

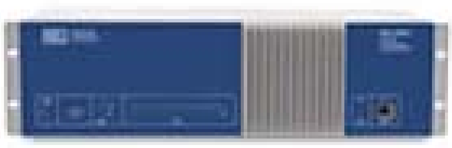
The tangible results so far (June 2011)

- ***19 organizations are participating in the project, providing 100% coverage for the Western Interconnection***



Regional Footprint

Phasor Measurement Unit



Phasor Data Concentrator

Meta-Analyses Reports

Analyze results from SGIG, SGDP, and RDSI

1. Summarize results
   - ✓ Report similarities, differences, and range of results
   - ✓ Rationalize results
   - ✓ Common best practices and lessons learned
   - ✓ Connect investments with functions with benefits
   - ✓ Connect smart grid with improved DER functionality

2. Educate

Meta-Analyses Reports

- Dynamic Line Rating
- Microgrids
- Distributed Energy Resources
- Communications Network
- Conservation Voltage Reduction
- Business Case Library
- Consumer Behavior Studies
- Value of Service
- AMI/smart meter
  - O&M
  - Peak load reduction
  - Volt/VAR optimization
  - Reliability

Life After ARRA Smart Grid Program

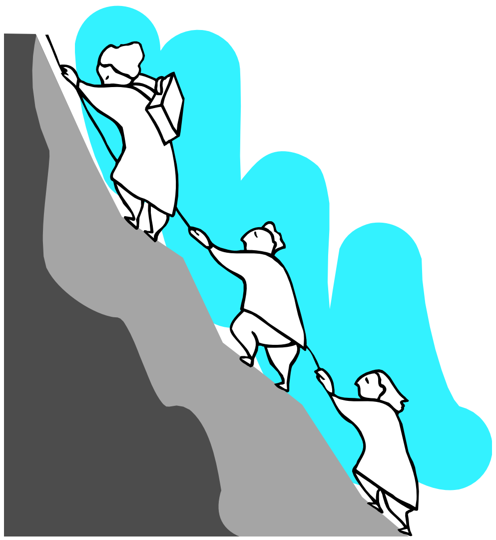
Life After ARRA Smart Grid Program

Build and maintain momentum

- Make business case
- Identify, allocate, and quantify benefits
- Identify and quantify costs
- Address technical issues
- Address regulatory issues
- Address customers concerns

Additional Challenges

- Address technical issues
  - Standards
  - Two-way communications
  - Data management
  - Central and distributed controls
  - Protection
  - Cyber security
- Address regulatory issues
  - Used and useful & least cost
  - Recovery of investment cost
- Address customers concerns
  - Privacy
  - Convenience, comfort, and benefits
  - Understanding
  - Health and safety



Contact Information

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Federal Smart Grid Website
www.smartgrid.gov

Smart Grid Clearinghouse
www.sgiclearinghouse.org/

DOE Office of Electricity Delivery and Energy Reliability
www.energy.gov/oe/technology-development/smart-gridwww.smartgrid.gov

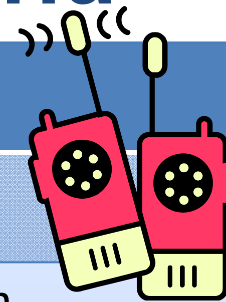
NETL Smart Grid Analyses
www.netl.doe.gov/smartgrid/index.html

Questions ?

Future Grid Modernization

Possible concepts for future modern grid
Shifts in technologies & business models
Technical, regulatory, and cultural challenges
Concepts are not fully developed
Short and long-term vision
List is not comprehensive
Feedback is encouraged

What's Different with a Modern Grid



Current Grid	Modern Grid
Little consumer engagement	Consumer involvement
Radial system	Networked and integrated system
One-way power flow	Two-way power flow
One-way communications	Two-way communications
Central generation	Mix of central and distributed generation
Passive control	Active control
Fixed rates	Dynamic rates
Separate transmission & distribution	Interaction between T&D
Little ties with other infrastructures	Potential to transform transportation sector

Ancillary Services

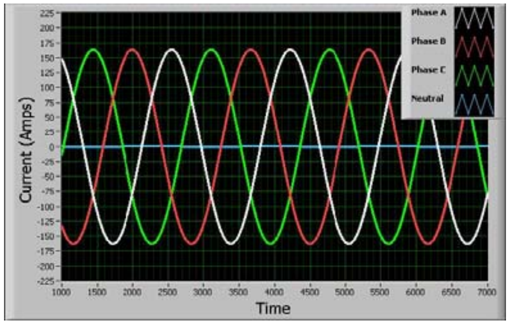
From FERC: Ancillary Services "necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system."

System control, voltage control, regulation, load following, spinning reserve, supplemental reserve, backup supply, energy imbalance, real power loss replacement, dynamic scheduling, black start, network stability

Future Grid Modernization

Changes in ancillary services

- Change in ancillary service requirements
  - Reserve margins could be re-evaluated considering distributed and consumer assets
  - Solid-state power electronics, energy storage, DG
- Change in technical approach for ancillary services
  - Growth of distributed and consumer assets
- Change in ancillary service market
  - Value of VAR
- Value
  - Value of reliability and power quality

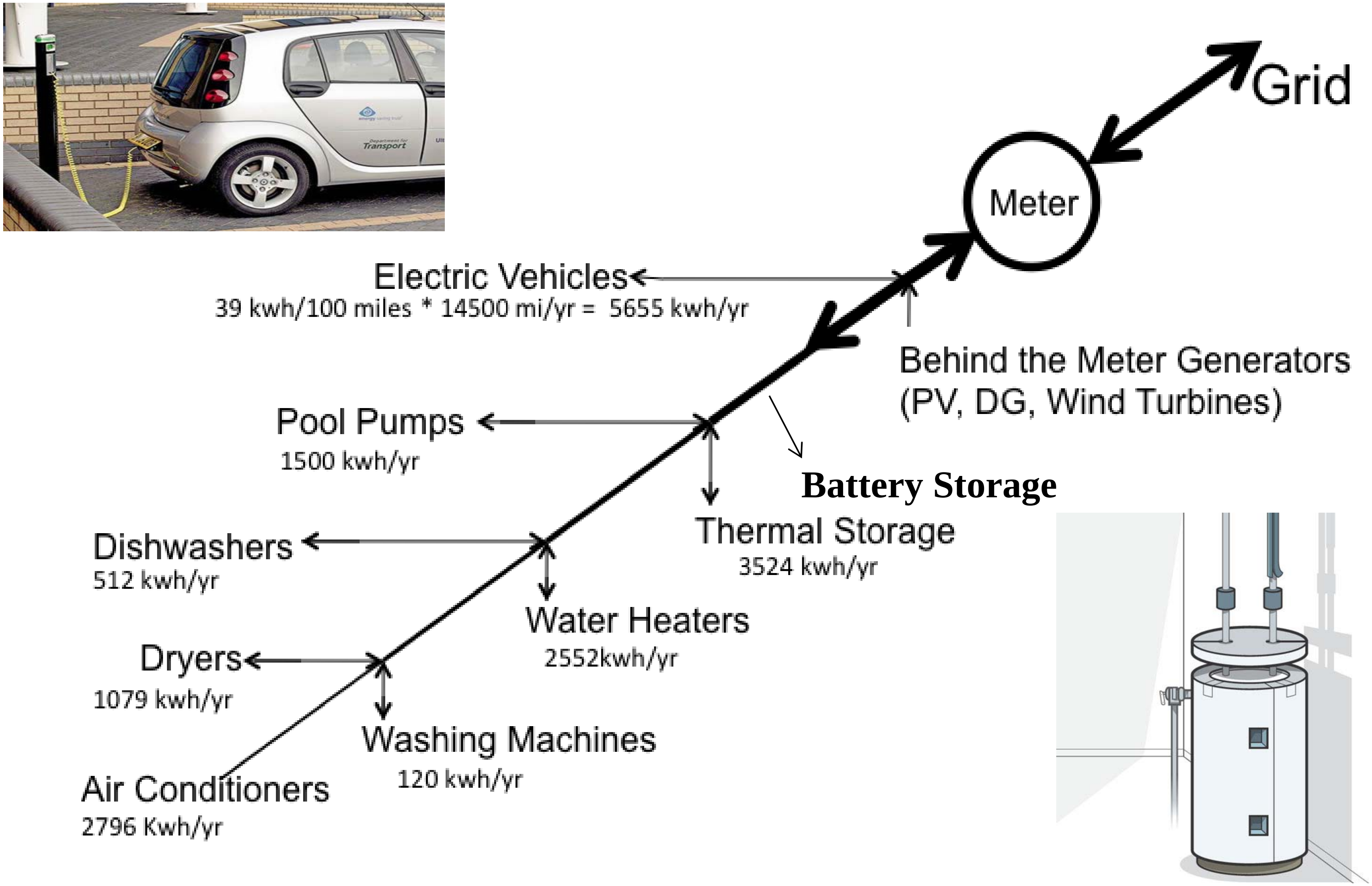


Future Grid Modernization

Growth of demand dispatch

"An operating model used by grid operators to dispatch "behind-the-meter" resources in both directions—increasing and decreasing load as viewed at the system level—as a complement to supply (generation) dispatch to more effectively optimize grid operations."

Are there enough resources to make DD work?



Future Grid Modernization

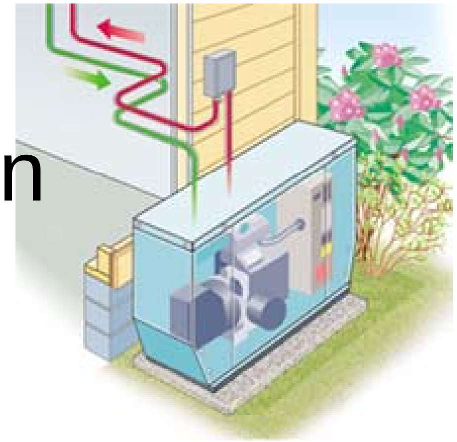
Higher levels of power quality

- Frequency and voltage control in narrow range
- Furnished by electric service provider or consumer?

- Tiered pricing and value
- Addresses both critical loads (i.e., outages) and sensitive loads (i.e., power quality)
- Movement on Conservation Voltage Reduction

Future Grid Modernization

- Backup generation connected to grid
  - Additional source of distributed generation
  - BUGs participates in grid operation
    - Serves load and ancillary services
  - Serves critical loads of customer-owned BUGs and other customers
  - Assists in stabilizing grid operation



Future Grid Modernization

Dynamic line rating increasing power flow

- Real-time rating of transmission capacity
- Addresses transmission congestion
- Improves financial aspects of G&T

Future Grid Modernization

Greater interaction between T & D

- Distributed assets alleviate transmission congestion
- Transmission and main grid distribution assets alleviate microgrid congestion
- Better communication between T&D operations
- Merging of wholesale and retail markets
- Optimization of entire power system
- Coordinate GT&D to gain efficiency

Future Grid Modernization

Interesting dynamics of consumer behavior in demand response

- more participation in demand response provides less benefit to each customer
- consumer behavior study
  - Retention in DR
  - Level of participation in DR
- limits of consumer behavior (e.g., hot days)

Future Grid Modernization

Shift to more hybrid AC/DC systems

- in both transmission and distribution
- DC microgrid connection to AC grid
- reduce number of power converters

Future Grid Modernization

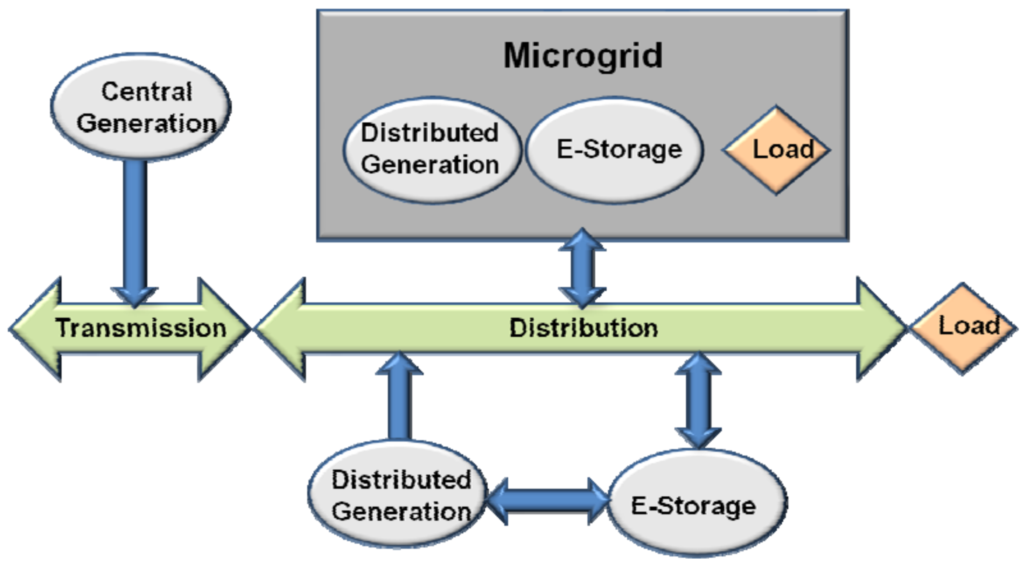
Integration of systems and processes of electric service providers

- improved efficiency, communications, and teamwork
- operations, maintenance, OMS, billing, customer service, engineering, planning, traders, procurement, workforce scheduling, …
- Weather forecast, adjust schedules, check inventories, assemble crews & tools
- Integration of power, communications, and market software

Future Grid Modernization

Growth of smart microgrids

- Microgrids with CHP and other poly-products
- Greater flexibility in meeting power needs
- Serve critical loads
- Desire to become more self sufficient



Future Grid Modernization

Growth of distributed energy resource aggregators

- Demand response
- Distributed and consumer generation
- Energy storage (e.g., electric vehicles, community storage)

Future Grid Modernization

Move to ultra-high voltages in transmission

- both AC and DC power transmission
- greater than 1000 kV
- reduced electrical losses

Feedback

Feedback

- Comments on vision of future grid modernization
  - Expand on proposed idea(s)
  - Additional applications

- Offer other concepts of grid modernization

- Perspective on remaining barriers