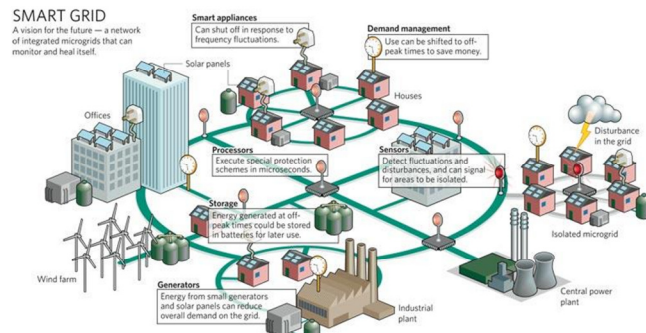


An Introduction - Smart Grid 101

Chapters 1-3



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February 2010

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2/7/2011

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The Smart Grid is a compilation of concepts, technologies, and operating practices intended to bring the electric grid into the 21st century.

Defining the smart grid is difficult for several reasons. First, there is no single template that defines exactly what the smart grid will look like or how it will operate in any given service area. Without a consensus template people tend to construct their own mental vision of how the technologies, systems, and customers will interact. There is also the reality that customer mix, geography, weather and other factors will almost certainly make the smart grid in each service area a little unique.

The second factor contributing to the uncertain definition is the fact that the smart grid does not yet exist. Many of the systems and technologies expected to become a part of smart grid either haven't been developed yet or are in prototype or early stages of testing and implementation.

It is difficult to define something that does not exist. While these factors attach a degree of uncertainty to smart grid, there are several foundational concepts, technologies, and regulatory practices that define smart grid expectations.

The purpose of this Smart Grid 101 tutorial is to identify what we know and to clarify key questions to help reduce the unknown.

Smart Grid 101

Chapter	Slides
1. Define Smart Grid	4-12
2. A Smart Grid Vision	13-19
3. Reliability	20-28

This first segment of the Smart Grid 101 tutorial includes three chapters. Each chapter addresses one of the key domains that contribute to the smart grid vision.

While the scope of smart grid covers the entire utility system from generation to how customers use energy, this tutorial primarily focuses on the intersection between the distribution system and customers. All elements of smart grid include important engineering, economic, and policy issues. However, with the exception of alternative generation options, the generation and transmission segments are less uncertain and more dominated by engineering economics than the distribution and customer segments.

1.0 Define Smart Grid

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From a regulatory perspective, a clear definition of smart grid is important for two reasons. First, it helps if consumers, utilities, vendors and regulators all start from a common understanding of smart grid. Second, how smart grid is defined establishes the framework to guide expectations, resource allocation decisions, and implementation priorities.

However, coming up with a simple, universally accepted definition of the smart grid is not an easy task. While everyone generally agrees that the term “smart grid” implies a modernization of the existing electric system, there are divergent opinions on how modernization translates into specific policy actions or resource decisions.

If you were to start from scratch today to design an electric system for your community, what would it look like ?

Consider the following question.

“If you were to start from scratch today to design an electric system for your community, what would it look like?”

This is a key challenge for creating a smart grid.

Designing a system from scratch, starting with no legacy systems and no rules, allows you to identify how best to incorporate new technologies and designs and to achieve the objectives most important to you. Your neighbors design and objectives may not exactly match yours, which is exactly the problem we encounter today in defining smart grid. Everyone has slightly different perspectives, which results in different designs and objectives.

Once your new smart grid is designed, you have established the vision or where you “want to be”, which makes it possible to compare your future grid, with “where you are”, the current grid.

These differences are critical because they establish a benchmark and framework for determining what you have to do to transition to a smart grid.

1.2 Define Smart Grid



Three Questions

1. What is a “Smart Grid” ?
2. How is a Smart Grid different from the existing grid ?
3. Why do we need it?

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To define smart grid we have to answer three basic questions.

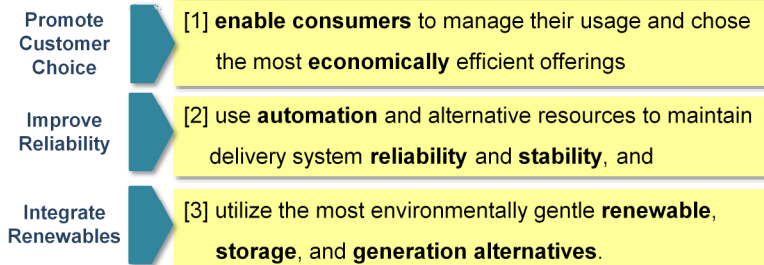
1. What is a smart grid?
2. How is a smart grid different from the existing utility grid?
3. Why do we need it?

1.3 Define Smart Grid



Smart Grid is System Integration

The Smart Grid is a system of information and communication applications integrated with electric generation, transmission, distribution, and end use technologies which will :



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Question 1: WHAT IS SMART GRID ?

Fundamentally, smart grid is a combination of information and communication applications that link together generation, transmission, distribution, and customer end-use technologies. The need to integrate all of the systems that generate and supply energy with customer usage is one of the very certain design principles of smart grid. System integration will be accomplished using information and communication systems .

Smart grid is not necessarily a specific combination of parts as much as it is a process for using information and communications to integrate all the components that make up each electric system. Smart grid is system integration.

The smart grid system integration process shares three common objectives:

1. Promote customer choice – provide customers with information, rates and pricing, and technologies that will allow them to make better usage decisions;
2. Improve reliability – use automation on the grid and in customer premises as well as alternative generation options to improve system reliability and stability, and
3. Integrate renewables – support alternative generation and storage options that minimize or reduce environmental impacts, improve overall system efficiency, and reduce carbon-based fuel usage.

Note: Title XIII, Section 1301 of the Energy Independence and Security Act of 2007 describes smart grid as a system capable of accomplishing ten specific objectives

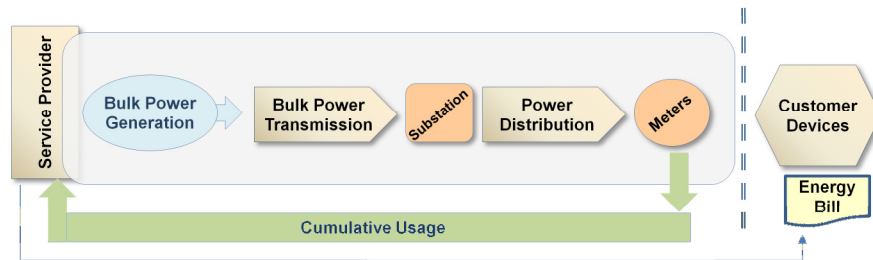
http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf

1.4 Define Smart Grid



The Existing Utility Grid

- ❑ Centralized generation
- ❑ Power flows from the utility to the customer
- ❑ Periodic billing



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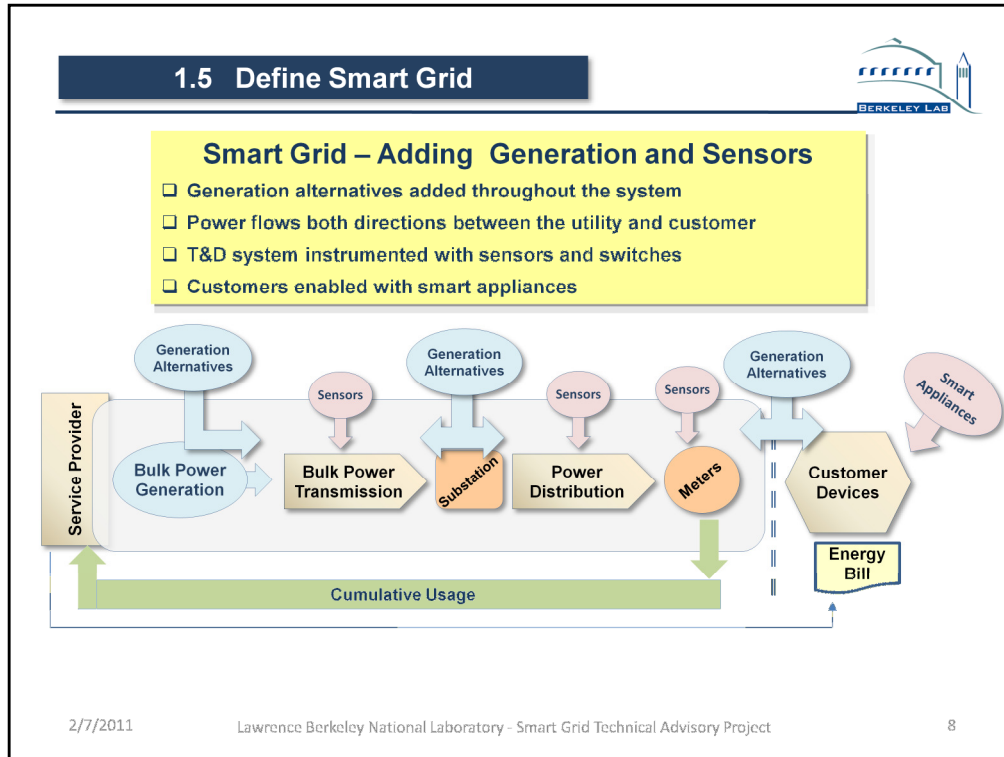
7

Question 2: HOW IS A SMART GRID DIFFERENT FROM THE EXISTING GRID ?

The existing utility grid is a centralized system where power flows in one direction, from generation resources through the transmission-distribution system to the customer. Generation may or may not be located in the same geographic area as the load being served, which can often require transmission from distant locations.

Existing utility grids may or may not include Supervisory Control and Data Acquisition (SCADA) sensors, computing, and communications to monitor grid performance. Utility systems may depend instead on separate reporting systems, periodic studies, and stand-alone outage management applications.

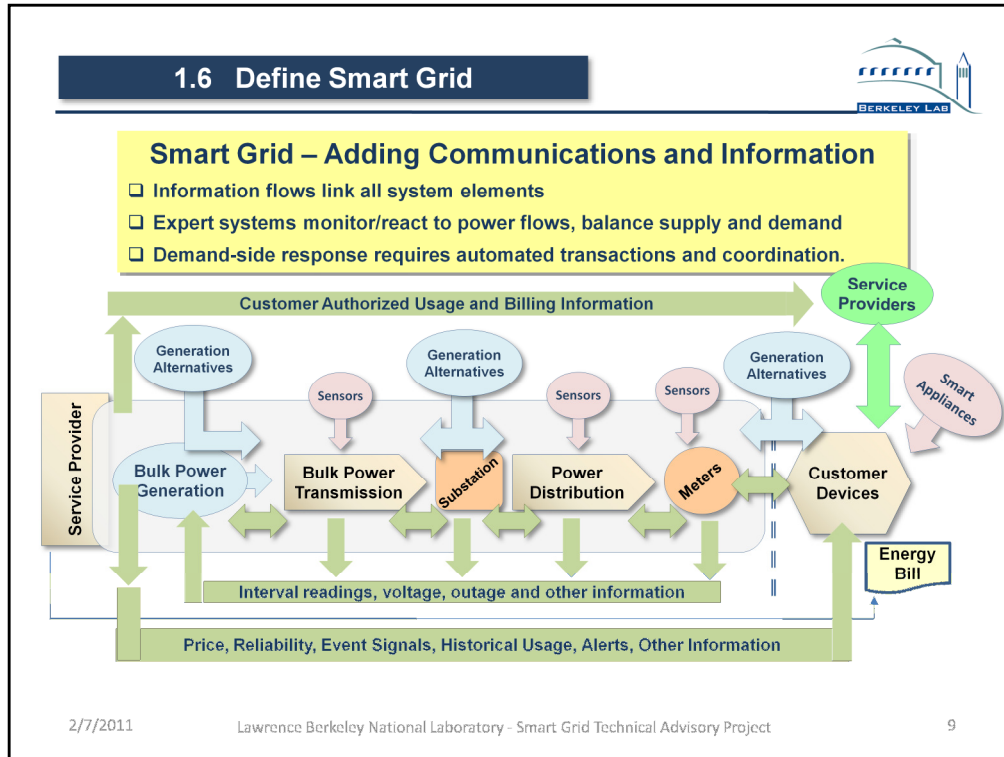
Information to the customer is generally limited to a periodic bill for services consumed in a prior time period or billing cycle. Utility web sites may or may not provide customers will access to their usage data. Energy usage is usually presented as an aggregate kWh value for a specific billing cycle, which may or may not align with monthly calendar boundaries.



Question 2(continued): HOW IS SMART GRID DIFFERENT FROM THE EXISTING GRID ?

The first step to transform the existing grid into a smart grid requires the addition of generation options throughout the grid at bulk power transfer points, substations, other distribution locations and on the customer side of the meter. Adding generation throughout the grid allows power sources to be located closer to their point of use, reducing investment in transmission and distribution, and in many cases reducing energy losses. Implementation of widespread, smaller generation resources diversifies supply, reduces risks of major outages, and improves overall reliability.

Sensors, remote monitoring, automated switches, reclosers, upgraded capacitor banks, and other equipment may be integrated into the grid to provide end-to-end monitoring and control of the transmission and distribution network. Equivalent additions on the customer side of the meter would include automated control systems and smart appliances with embedded price and event-sensing and energy management capability. Sensors provide the information to better understand grid operation, while control devices provide options to better manage system operation.



Question 3. WHY DO WE NEED A SMART GRID?

The last stage necessary to transform and create a smart grid is the addition of communication systems to support information flows that fully link both the utility and customer sides of the grid.

On the utility side of the grid, sensors will be integrated with high speed switches and expert systems to automatically balance power flows, isolate and re-route power around disturbances , report outages, and continuously update system operators with weather, demand, and performance data from throughout the system.

On the customer side of the grid, near real-time meter data will be available so customers can better understand how individual appliances and behavior impact their energy usage and costs. Broadcast price, reliability and event signals may be monitored directly by smart appliances or through home automation gateways , responding automatically to customer preferences to defer or reduce usage during high-priced or constrained reliability periods. Third-party service providers may also provide customers with a range of information and energy management services.

1.71 Define Smart Grid



Feature	Current System	Smart Grid
Utility Business Model	<ul style="list-style-type: none"> Utility Centric ownership Centralized operation 	<ul style="list-style-type: none"> Distributed ownership Distributed operation
Obligation to Serve	<ul style="list-style-type: none"> Utility Provides All Customer Pays 	<ul style="list-style-type: none"> Utility Provides Some Customer Pays
Generation Resources	<ul style="list-style-type: none"> Centralized Thermal dominates 	<ul style="list-style-type: none"> Distributed Renewable emphasis
Transmission / Distribution	One Way Power Flow	Two Way Power Flows Micro Grids
Metering- Measurement	Accumulated Usage	Interval Measurement
Rates (Pricing)	Rates not Pricing	Actionable Prices
Customer Role	Passive	Active

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Question 3 (continued). WHY DO WE NEED A SMART GRID?

This table lists seven attributes that further distinguish specific differences between the existing grid and a smart grid. Distinguishing specific differences between the existing grid and a smart grid helps frame the technological and operational differences that help answer 'WHY do we need a smart grid'. Some of the advantages include:

1. **Utility Business Model:** In a smart grid, ownership and operation is distributed between the utility, third-party providers and the customer. Distributing asset ownership could work to reduce overall long-run costs and spur innovation in generation sources.
2. **Obligation to Serve:** For the current electric grid, the traditional regulatory compact provides utilities with exclusive, sole-provider operating rights and in return obligates them to provide safe reliable service to all customers. With a smart grid, the regulatory compact is broadened to now allow third-party retail service providers and customers to provide additional energy information and management services. Reliability services may become more customized and tailored to each customer's specific needs and preferences. Under this new compact the customer is expected to have more choice regarding the services received and what they pay.
3. **Generation Resources:** Under a smart grid, more generation resources are expected to become distributed throughout the grid. Distributing generation throughout the grid is expected to improve reliability, reduce the need for transmission expansion, reduce major siting issues, and encourage applications of alternative renewable options.

Question 3 (continued). WHY DO WE NEED A SMART GRID?

4. Transmission / Distribution: Systems designed to transport power from centralized locations will under smart grid migrate to self-contained micro-grids and localized generation sources.
5. Metering-Measurement: Advanced metering is expected to provide the interface between the utility and customer, to provide CUSTOMER access to more detailed usage data, and a foundation for more relevant action-oriented customer education. Advanced metering will also provide capability to provide a much wider range of pricing options including pre-payment and innovative dynamic rates. Finally, advanced metering infrastructure (and near real-time communications) supports expanded demand response opportunities including enabling customer participation in ancillary services markets.
6. Rates (Pricing): Under the existing conventional grid, rates are reasonably static, changing infrequently, where their primary purpose is to compute a periodic bill. In a smart grid environment, rates will take on an active day-to-day operational role to facilitate not only expanded demand response but also facilitate integration of large-scale intermittent renewable generation, electric vehicles, and other localized options.
7. Customer Role: Under smart grid, customers are expected to become more active participants in how they obtain and use energy. That doesn't mean that customers will have to stand around and monitor energy prices in real time, however it does mean that customers will be provided with more information to better inform them regarding how they use energy, what it costs, and options for changing and automating their energy usage habits to better control their costs.

1.8 Define Smart Grid



References

	Title	Link
1	Smart Grid: Enabler of the New Energy Economy, December 2008	http://www.oe.energy.gov/DocumentsandMedia/final-smart-grid-report.pdf
2	The Smart Grid: An Introduction, October 2008	http://www.oe.energy.gov/DocumentsandMedia/DOE_SG_Book_Single_Pages(1).pdf
3	Evolution and Progress of Smart Grid Development at the Department of Energy, July 2008	http://www.naraconferences.org/Presentations/Evolution%20and%20Progress%20of%20Smart%20Grid%20Development.pdf
4	Metrics for Measuring Progress Toward Implementation of the Smart Grid, June 2008	http://www.oe.energy.gov/DocumentsandMedia/Smart_Grid_Workshop_Report_Final_Draft_08_12_08.pdf
5	What will the Smart Grid Look Like?, June 2008	http://www.netl.doe.gov/moderngrid/referenceshell/0E-008Optimizer-FACT%20SHEET_APPROVED_2008_06_17.pdf
6	Energy Independence and Security Act of 2007	http://freebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf
7	Vision for the Modern Grid, March 2007	http://www.netl.doe.gov/moderngrid/docs/A%20Vision%20for%20the%20Modern%20Grid_Final_v1.0.pdf
8	"Grid 2030": A National Vision for Electricity's Second 100 years, July 2003	http://www.oe.energy.gov/DocumentsandMedia/Electric_Vision_Document.pdf

2.0 A Smart Grid Vision

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A Smart Grid vision communicates an image of the future. What will the grid look like in 5, 10, or 20 years? Who will own the parts, who will pay for them, and will we use energy differently than we do today? A Smart Grid vision defines our expectations for what it looks like, how it operates, and what it costs. While defining Smart Grid is difficult, coming up with a consensus Smart Grid vision would be extremely difficult. There are just too many unresolved technology and policy uncertainties to support a consensus vision. Instead it is possible to identify and agree on several key elements that will be essential to Smart Grid under any set of circumstances. Achieving agreement on fundamental expectations will provide a framework for establishing initial technology, policy, and implementation priorities.

2.1 A Smart Grid Vision



One of Many Visions *

Regulator

Cost Effectiveness,
Economic Efficiency,
Equity

Utility

Cost Recovery

Customer

Value, Privacy

- ☐ ..expand the infrastructure for moving electricity from where it is generated to where it is needed
- ☐ ..accommodate distributed energy from local areas and,
- ☐ Make the grid 'smart' so that it can monitor and balance the load,
- ☐ ..capitalize on a massive national fleet of clean plug-in cars.

* Al Gore's 'Unified Smart Grid' vision for repowering the USA - will it happen?, November 8, 2008,
<http://blogs.zdnet.com/collaboration/?p=160>

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In general the Smart Grid vision and expectations are driven by three different perspectives.

1. Regulatory Perspective: Regulatory decisions must balance the new investment necessary to provide reliable service at reasonable cost (which may translate into limiting cost increases), promote economic efficiency and development, and ensure fairness to all customer classes.
2. Utility Perspective: Smart Grid will require significant capital investment (in AMI and other T&D assets) which is consistent with the IOU business model. However Smart Grid may also constrain traditional IOU investment by encouraging demand response (DR) and dynamic pricing, energy efficiency (EE), and increased customer or third-party ownership of renewable resources. While Smart Grid creates opportunity consistent with the IOU business model it also creates a risk that successful DR, EE and non-utility ownership will reduce corporate earnings and shareholder value. The conflict between potential rewards and risks definitely influences IOU Smart Grid investment and implementation perspectives.. Municipal utilities don't contend with the IOU profit or shareholder objectives, however they have to be much more cognizant of balancing new investment with potential rate increases.
3. Customer Perspective: Customers want to see service and value for the dollars spent.

The expectations or vision for Smart Grid can vary substantially depending upon which perspective you take. While the four bullet points on this slide don't fully capture all of the Smart Grid vision, they provide at least one example that bounds many of the general expectations.

2.2 A Smart Grid Vision



Basic Questions

1. What problem(s) are you trying to solve: manage future costs, improve reliability, or integrate renewables ?
2. Which perspective(s) are you trying to serve: society, end-user (rate payer), or the utility ?
3. How is the "Smart Grid" different from what you've already been doing ?
4. What are the costs and benefits of implementing Smart Grid?
5. Where do you start and what information do you need to proceed: [1] Pilot programs or [2] a Transition Plan ?

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Developing a Smart Grid Vision

The previous slide identified different perspectives of smart grid, first the generalized perspectives representing the three major participants in each electric system and second, an early, more specific national policy perspective.

One conclusion that should be drawn from these different perspectives is that a consensus opinion regarding Smart Grid expectations will be difficult to achieve. What makes achieving consensus even more difficult is that implementation decisions need to be resolved against what can often be unique local needs and requirements.

This slide poses a series of five questions that should be resolved for any Smart Grid implementation. These questions also represent typical issues and concerns raised by many state commissions in the midst of Smart Grid proceedings.

These questions also provide the guidance for all the remaining information in this tutorial.

1. What problem(s) are you trying to solve: manage future costs, improve reliability, or integrate renewables?
2. Which perspective(s) are you trying to serve: society, end-use (rate payer), or the utility?
3. How is the "Smart Grid" different from what you've already been doing?
4. What are the Smart Grid costs and benefits?
5. Where do you start and what information do you need to proceed: [1] Pilot programs or [2] a Transition Plan?

2.3 A Smart Grid Vision



Attributes

1. PHEV's 2. Advanced Metering 3. Dynamic Rates 4. Sensing
5. Automation 6. Expert Systems 7. New Technology

	Claimed Societal Benefits	Attribute	Realistic ?
1	Dramatic reduction in tailpipe emissions	1-6	
2	Reduction in petroleum imports of >50%	1-5	
3	Reduction in peak loads – lowering prices for consumers	2, 3, 5	
4	Improved grid reliability	4-6	
5	Increased grid security	4-6	
6	Positive environmental impact	1-7	
7	Enable new products, services and competitive retail markets	3	
8	Anticipate and respond to system disturbances (self-heal)	4-6	
9	Perform continuous self-assessment, respond faster by supplementing human operators.	4-6	
10	Operate resiliently against attack and be less vulnerable to natural disaster	4-6	

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This table and the two that follow provide much more specific lists of expected Smart Grid benefits categorized into the regulator or societal, utility, and customer perspectives. Each table of benefits is characterized by a list of seven attributes that correspond to the expected source that will produce or contribute to achieving the benefit. The final column in each table poses a question that asks if a benefit is “Realistic ?”.

The entries in the “Realistic” column for each of the three tables of benefits is always left blank. The reason - Smart Grid is still too new and not far enough along in implementation to confirm whether any of these benefits will actually be realized. In addition almost all of the benefits require concurrent implementation of policy, rate, and technology options and some degree of customer participation or acceptance. This concurrent implementation or system integration element of Smart Grid is particularly uncertain.

All of the expected benefits in these three slides were culled from legislation or reports and presentations by proponents of Smart Grid.

This table lists ten (10) expected Smart Grid societal benefits. These benefits represent broad system wide expectations that should benefit utilities, customers, and society in general.

For example, increasing grid reliability is particularly difficult to measure. As will be pointed out later in this tutorial, there are few standards in place to govern reliability reporting or measurement and the common industry indexes and metrics already in use reflect a utility rather than customer centric valuation. The claimed reduction in petroleum imports provides another example, where the factors impacting this benefit include national and international politics, economics and environmental issues that go far beyond the Smart Grids anticipated by any individual utility.

2.4 A Smart Grid Vision



Attributes

1. PHEV's 2. Advanced Metering 3. Dynamic Rates 4. Sensing
5. Automation 6. Expert Systems 7. New Technology

Claimed Consumer Benefits ^(slide 18)		Attribute	Realistic ?
1	Equivalent of \$1.00 per gallon for gasoline	1	
2	Provide prices and opportunity to buy when KWh prices are low and sell when high	2-7	
3	Home back-up power and mobile resource	1, 2-7	
4	Protecting against power losses and avoiding costly interruptions and spoilage	2-7	
5	Reducing the cost of electricity during peak power periods,	2-3	
6	Customer choice from products to services	2, 3	
7	Enhanced system reliability	2, 3	
8	Enable active participation by consumers	2, 3, 5, 7	
9	Power quality at different prices	2, 3, 5	
10	Consumers access to information, control and options that allow them to better manage energy and environmental costs	2, 3, 5, 7	

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This table lists ten (10) expected Smart Grid consumer benefits. Several of the benefits listed here duplicate those in the preceding slide. However, each of these benefits will require new policy and technology implementation.

For example, providing customers with prices and opportunities to buy and sell energy (benefit #2) will at a minimum require three complimentary actions: (1) adoption of time differentiated or dynamic rates, (2) incentives to encourage customers to acquire and operate distributed resources, and (3) either net metering provisions that allow customers to sell excess energy back to the grid or more widespread competitive and open energy markets. Advanced metering to facilitate the rates, sensing and automation technology to manage load, and expert systems to guide 'use or sell' opportunities will all be required to support this claimed benefit. There is no benefit without advanced metering or dynamic rates.

2.5 A Smart Grid Vision



Attributes

1. PHEV's 2. Advanced Metering 3. Dynamic Rates 4. Sensing
5. Automation 6. Expert Systems 7. New Technology

Claimed Utility System Benefits* (slide 18)		Attribute	Realistic ?
1	Minimizing energy transmission losses	7	
2	Improving the efficiency of the electricity grid.	2-7	
3	Increased efficiency of power delivery	2-7	
4	Extended asset life	?	
5	Seamlessly integrate generation and storage options	[2,3,5] [4-7]	
6	Operate efficiently to improve load factors, lower system losses, and improve maintenance.	[2,3,5] [4-7]	
7	Grid operators have new resource options to provide energy, capacity and ancillary services	[2,3,5] [4-7]	

Sources

1. The Smart Grid – Benefits and Challenges, EEl Annual Convention, J.Miller – Modern Grid Strategy Team, June 16, 2008
2. What will the Smart Grid Look Like?, A Vision for the Smart Grid., DOE Office of Electricity Delivery and Energy Reliability, June 2008.
3. Miscellaneous public reports, press releases, presentations, and private sources.

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This table lists seven (7) expected Smart Grid utility benefits. What is unusual about this list of benefits is that none address utility profitability, earnings, or impacts on shareholder equity. While we could have added utility specific financial benefits the intent was to reflect how Smart Grid is reflected in industry related publications and venues. Obviously, utility financial, operational, and shareholder benefits (for investor owned utilities) are all important in assessing the value of Smart Grid and should be included in any evaluation.

What is apparent from the listed benefits in three preceding tables is that many of the claimed benefits for Smart Grid are prospective, difficult to measure, and in many cases uncertain because they are dependent upon policy, economic, and political factors beyond local control. Because Smart Grid is defined as a system integration effort, the benefits naturally reflect the expected long-term system integration benefits. As a result, it is difficult to generalize Smart Grid benefits from one implementation to another. This poses a difficult situation for local boards and state regulatory commissions that are obligated to assess the operational impacts, economics, cost-benefit, and expected value of proposed Smart Grid initiatives. One solution to this problem is to refocus on near-term expectations and benefits from the rate, metering, technology, and operational elements that will eventually create the Smart Grid and set aside the prospective industry promoted broad categories of benefits.

2.6 A Smart Grid Vision



References

	Title	Link
1	Al Gore's 'Unified Smart Grid' vision for repowering the USA - will it happen?, November 8, 2008,	http://blogs.zdnet.com/collaboration/?p=160
2	The Smart Grid – Benefits and Challenges, EEI Annual Convention, J.Miller – Modern Grid Strategy Team, June 16, 2008	http://www.oe.energy.gov/DocumentsandMedia/SG__Benefits_Challenges_J_Miller.pdf
3	What will the Smart Grid Look Like ?, A Vision for the Smart Grid, DOE Office of Electricity Delivery and Energy Reliability, June 2008	http://www.cnt.org/news/media/vision-2-pager-final.pdf

3.0 Reliability

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When customers “flip the switch” they expect their lights to go on and stay on. Local storm or accident caused outages can be disruptive and costly, however customers are generally accepting that certain acts of nature are inevitable and must be tolerated. Forced outages or rotating blackouts, like those instituted in California during their energy crisis of 2000-2001 generate very different adverse customer reactions because they are considered avoidable, they can create significant financial hardships for all customers (and the utility if it results in inappropriate policy or legislative intervention).

While improved reliability is considered one of the major benefits of Smart Grid, there are emerging concerns regarding the real value of claimed benefits versus the investment required. First consider that reliability improvements are not a unique function of Smart Grid. Improvements to the transmission and distribution grid are continuous, normal activities necessary to maintain and operate the grid. Adding automation, SCADA, and outage management capability have also been common to utility systems for at least 30 years.

However, under Smart Grid potential reliability improvements expand beyond the normal distribution grid to include the integration of distributed generation, renewables, and micro grids on a large scale. Here is where the three perspectives outlined in slide #2.1 play a significant role in helping to address the appropriateness of reliability Smart Grid improvements.

3.1 Reliability



Defining Reliability

"In brief, reliability has to do with total electric interruptions - complete loss of voltage, not just deformations of the electric sine wave. Reliability indices typically consider such aspects as :

- **the number of customers affected;**
- **the connected load;**
- **the duration of the interruption measured in seconds, minutes, hours, or days;**
- **the amount of power (kVA) interrupted; and**
- **the frequency of interruptions. "**

Source: Measurement Practices for Reliability and Power Quality, ORNL/TM-2004/91, June 2004, pg.3.

<http://www.ornl.gov/sci/btc/apps/Restructuring/ORNLTm200491FINAL.pdf>

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The accepted industry definition of reliability is limited to total electric interruptions or a complete loss of voltage. The value of reliability then becomes a function of the scope of the outage defined by the bulleted list of factors such as number of customers, their connected load, and the duration of the interruption.

Customer outage cost is a key factor missing from this bulleted list. An outage on a feeder serving 1000 small residential customers with 5MW of load will probably experience different losses (damage function) than a children's hospital, chicken farm, or public safety complex with the same load. Customer outage costs are important because they 'calibrate' the value of an outage, however customer outage costs are usually excluded from utility and regulatory outage measures because they are considered difficult to measure and somewhat subjective.

Can you measure reliability without including customer outage costs?

3.2 Reliability



What are the Objectives ?

1. Reduce the Frequency of outages ?
2. Reduce Outage Duration ?
3. Contain the Magnitude / Scope of outages ?
4. Improve Customer Notification ?
5. Reduce Unserved kWh ?
6. Reduce Customer Outage Costs ?
7. Reduce the Outage Damage Function ?
8. Improve Reliability Indices ?
9. Improve Power Quality

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With any investment, the first step is to identify and define the objectives. Nine illustrative questions are provided that address potential reliability improvements linked to the definition of reliability.

Metrics that measure current system conditions in response to each question establish the benchmarks against which investment objectives could be developed. These questions are not mutually exclusive in that several could be combined to establish a more robust set of objectives. These questions are also only examples. They don't represent a complete inventory of possible reliability objectives.

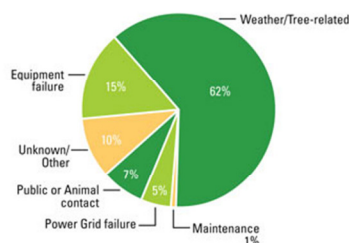
3.3 Reliability



Major Causes of Power Outages in the U.S.

Detroit Edison Example

Major causes of power outages in the U.S.



MOST CUSTOMER OUTAGES RESULT FROM DISTRIBUTION SYSTEM PROBLEMS, NOT TRANSMISSION OR GENERATION EVENTS

* Tracking the Reliability of the U.S. Source: <http://my.dteenergy.com/home/powerProblems/electricityOut/index.html>

Momentary outages *

- ☐ Result from interference on power lines caused by animal or tree branch contact.
- ☐ Usually last for a few seconds or less.
- ☐ Automatic devices on power lines quickly isolate the problem and typically restore power within moments.

Sustained Outages

- ☐ Planned or accidental total loss of power caused by storms, accidents or equipment damage.
- ☐ Usually last more than five minutes.

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Understanding the major causes and value of outages is necessary before reliability objectives can be established or evaluated.

This graphic example illustrates the distribution of outages by 'cause' reported for Detroit Edison Company*, a Midwestern utility. This pie chart shows that weather, unknown, and outside contact with the grid accounts for 79% of the system outages and only 5% are due to power grid failure. The distribution of outage minutes by these same causal factors would provide a more meaningful metric to address grid reliability improvements. Outage objectives and investment value would be quite different if the 5% of outages associated with power grid failure also account for 95% of the total outage minutes.

* Tracking the Reliability of the U.S. Source:
<http://my.dteenergy.com/home/powerProblems/electricityOut/index.html>

3.4 Reliability



Reliability Metrics

System Average Interruption Duration Index [SAIDI]

$$\text{SAIDI} = \frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Customers Served}}$$

System Average Interruption Frequency Index [SAIFI]

$$\text{SAIFI} = \frac{\sum \text{Number of Customer Interrupted}}{\text{Total Number of Customers Served}}$$

Customer Average Interruption Duration Index [CAIDI]

$$\text{CAIDI} = \frac{\text{SAIDI}}{\text{SAIFI}}$$

Momentary Average Interruption Frequency Index [MAIFI]

$$\text{MAIFI} = \frac{\sum \text{Total Number of Customers Momentary Interruptions}}{\text{Total Number of Customers Served}}$$

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The four formulas on this slide represent the common metrics used to evaluate utility reliability performance, however none of these metrics include factors to reflect the value of service or customer outage cost. While these metrics may reflect real improvements to utility system operating and maintenance practices, what still needs to be determined is whether reductions in the average duration of outages (SAIDI) or the average customer interruption duration (CAIDI) and any of the other measures adequately reflect material customer impacts.

Reliability Resources

- ❑ “Tracking the Reliability of the U.S. Electric Power System: An Assessment of Publicly Available Information Reported to State Public Utility Commissions”, J.Eto and K.Hamachi LaCommare, October 2008, LBNL-1092E, Ernest Orlando Lawrence Berkeley National Laboratory. <http://repositories.cdlib.org/lbnl/LBNL-1092E/>
- ❑ “Estimated Interruption Costs for Electric Utility Customers in the United States, Draft Report, February 2009, Freeman, Sullivan & Co., Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy. http://www.netl.doe.gov/moderngrid/docs/Cost_of_Power_Interruptions_to_Electricity_Consumers_in_the_.pdf
- ❑ IEEE Standard 1366-2003 Reliability Index and Major Event Definitions.

3.5 Reliability



Problems and Issues

❑ Bulk Power outages:

- Reported in near real-time to both NERC and DOE
- Reported to NERC on Form OE-417, "Electric Emergency Incident and Disturbance Report".

❑ Distribution outages

- Reported to state regulatory agencies
- No standard definitions or reporting for major and sustained outages.
- Power quality and momentary outages not addressed.

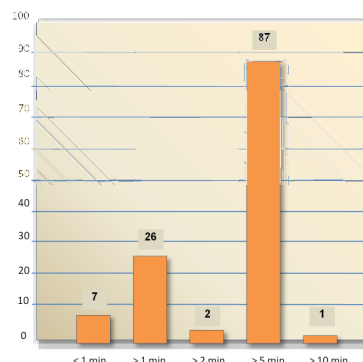


Figure 6. Utility Practices for Defining Sustained Interruptions^a

^a Electric Power Systems: An Assessment of Publicly Available Information Reported to State Public Utility Commissions, October 2008, Eto and LaComarre, Ernest Orlando Lawrence Berkeley National Laboratory.

This graphic illustrates another factor that needs to be weighed when considering reliability improvements. General utility practice is to only report outages with durations that exceed 5 minutes. This bar chart illustrates that 88 (70.4%) of the 125 utilities surveyed only report outages with durations exceeding 5 minutes. Historically short duration outages less than 5 minutes duration far outnumber those exceeding 5 minutes. Consequently, this reporting practice potentially misses a significant impact on customer experienced reliability. Defining the criteria for what constitutes an outage could materially impacts the technology fix and cost or outage improvement measures.

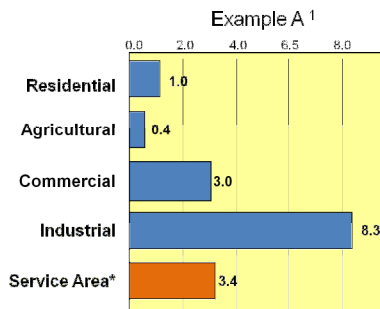
While statistical distributions that explain the cause and duration of outages are important, no combination of these statistics provides sufficient information to determine the cost effectiveness or priorities for new reliability investments. What's missing is a metric that reflects customer outage cost or value of service and how this valuation is impacted by the frequency and duration of outages. For example, outage costs that increase linearly as a function of outage duration would seem to justify investments that provide better detection, faster response, and a reduction in unserved energy (shorter outages). However, outage costs tend to vary significantly by customer class, so allocating reliability investments should be guided not just to reduce outage minutes but to reduce the most valuable outage minutes.

3.6 Reliability



Outage Costs

Outage Cost Relative to Residential Average**



*Represents the weighted average across customer types and aggregate customer usage for a 2-hour winter peak time outage.

[1] Source: Adapted from "Value Based Planning for Electric Utilities", CEC Report P300-87-001, December 1986.

Example B ²

Duration	Residential	Commercial	Industrial
0 Seconds	\$2.18	\$605	\$1,893
1 hour	\$2.70	\$886	\$3,253
Sustained Interruption	\$2.99	\$1,067	\$4,227

Outage cost normalized to Residential "1 hour".
Estimated Cost per outage.

[2] Source: Adapted from "Understanding the Cost of Power Interruptions to U.S. Electricity Customers", Hamachi, K and Eto, J, Lawrence Berkeley National Laboratory, Sept. 2004, Table 10, Tobit Regression Estimated Cost-per-Outage-per-Customer for the U.S. (US weighted 2002 dollars)

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This slide provides two examples of relative customer outage costs. While these examples use data from studies almost 20 years apart, the underlying relationship remains consistent – that outage costs differ substantially between customer classes and those differences have implications for resource allocation and grid management.

Example A illustrates the range of outage costs for an individual utility by customer class (blue bars) and for the aggregate service area averaged value over all customers (orange bars). Example B provides the U.S. average outage cost by customer class for three different outage durations. Example B also provides the outage costs normalized (in red) to the Residential 1-hour outage cost, to provide comparable metrics in Example A. To normalize the values in Example B all dollar outage costs were divided by the "1 hour" Residential value.

The objective of this slide is to illustrate the disparate value customer outage costs create in targeting and evaluating T&D reliability improvements. Weighting feeder, substation, and other grid improvements by customer outage costs would substantially change implementation and investment priorities. Variations in outage costs also have implications for how utilities target demand response options.

In this example, an investment to improve one of two feeders, one residential and one industrial, each with similar outage rates, all other things being equal, should favor the industrial feeder. Reductions in industrial outages will produce many times the benefit of a similar residential improvement.

Once the cause, characteristics, and value parameters have been established two key questions need to be resolved:

1. Will the proposed investments actually improve reliability? While outage minutes may be reduced, Example B indicates that momentary unreported outages still create a substantial cost.
2. Are there alternatives that might be more effective and less costly? Alternatives may include distributed generation, on-site renewables, storage and micro grid options.

3.7 Reliability



Defining and Measuring Reliability: Observations

1. There is no consistent definition, no universally applied industry standard for defining and reporting reliability [outages].
2. "Major" and "Sustained" events don't capture power quality (sags and surges) or "momentary" outages.
3. The value inherent in "outage management" is the reduction of the **customer outage cost**, which is a function of multiple variables including frequency, duration and customer type.
4. Which specific Smart Grid measures contribute to reliability improvements?

Clarify Objectives

- ☐ What are the reliability objectives (frequency, duration, cost...)?
- ☐ Is there more than one solution ?
- ☐ What reliability improvements will have the greatest impact?
- ☐ Where in the system will reliability investments have the greatest value?

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There are four key observations and conclusions that can be drawn from the previous slides on defining and valuing reliability in the context of Smart Grid.

1. There is no consistent industry definition for defining system reliability, particularly under a smart grid structure that considers alternative grid designs and distributed generation resources.
2. Existing industry definitions of reliability only report a portion of the events that impact customer service delivery.
3. The value component of reliability is customer outage costs, which is a function of many variables, may be difficult to estimate, and is not considered in current reliability metrics.
4. It is not clear which specific Smart Grid measures will contribute the most to system reliability improvements.

What is clear is that not all Smart Grid investments will produce equivalent benefits.

Regulators should be aware that they may have to consider and address the inadequate and incomplete definitions and the difficulty in establishing 'customer value' for reliability as part of their assessment of Smart Grid benefits.

3.8 Reliability



References

	Title	Link
1	Measurement Practices for Reliability and Power Quality, ORNL/TM-2004/91, June 2004, pg. 3.	http://www.ornl.gov/sci/btc/apps/Restructuring/ORNLTM200491FINAL.pdf
2	Tracking the Reliability of the U.S. Source:	http://my.dtesenergy.com/home/powerProblems/electricityOut/index.html
3	Electric Power System: An Assessment of Publicly Available Information Reported to State Public Utility Commissions, October 2008, Eto and La Commare, Ernest Orlando Lawrence Berkeley National Laboratory.	http://certs.lbl.gov/pdf/lbnl1092e-puc-reliability-data.pdf
4	Value Based Planning for Electric Utilities", CEC Report P300-87-001, December 1986	
5	Understanding the Cost of Power Interruptions to U.S. Electricity Customers, Hamachi,K and Eto,J, Lawrence Berkeley National Laboratory, Sept. 2004, Table 10.	http://certs.lbl.gov/pdf/55718.pdf
6	Tracking the Reliability of the U.S. Electric Power System: An Assessment of Publicly Available Information Reported to State Public Utility Commissions", J.Eto and K.Hamachi LaCommare, October 2008, LBNL-1092E, Ernest Orlando Lawrence Berkeley National Laboratory	• http://repositories.cdlib.org/lbnl/LBNL-1092E/
7	Estimated Interruption Costs for Electric Utility Customers in the United States, Draft Report, February 2009, Freeman, Sullivan &Co., Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy.	http://www.netl.doe.gov/moderngrid/docs/Cost_of_Power_Interruptions_to_Electricity_Consumers_in_the_.pdf

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