Smart Grid

Leveraging Intelligent Communications to Transform the Power Infrastructure

Authors
Venkat Pothamsetty
Saadat Malik

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Executive Summary

Smart grid is the term generally used to describe the integration of the elements connected to the electrical grid with an information infrastructure to offer numerous benefits for both the providers and consumers of electricity. It is an intelligent future electricity system that connects all supply, grid, and demand elements through an intelligent communication system. The backbone of a successful smart grid operation is a reliable, resilient, secure, and manageable standards-based open communication infrastructure that provides for intelligent linkages between the elements of the grid while participating in the decision making that delivers value to the utility and supply and demand entities connected to it.

The ability of a utility to create ubiquitous connectivity between all of its current data sources and decision-making points is critical to the success of smart grid. A communication infrastructure that can efficiently move disparate types of data with varying degrees of transport, security, and reliability requirements is indeed a central requirement. However, it is the ability of the communication infrastructure to participate and work together with the data providers, the decision-making entities, and the actuators to achieve the goals of the smart grid environment that truly brings about the business transformation utilities are aiming for.

Smart grid is a paradigm-shifting transition for utilities. Cisco's ability to transform a utility's environment from end to end through a converged intelligent network platform that becomes the fabric that optimally brings together all the value factors of a smart grid is Cisco's primary differentiator. Cisco has a history of proven commitment to taking markets through transitions. Data, voice, and now video are examples. With a strong and well-established ecosystem of partners, Cisco is today committed to becoming the trusted advisor and partner for the utility industry as it attempts to bring innovation and disruption to an environment ripe for change.

What Is Smart Grid?

The concept of a smart grid emerges from the integration of the power systems view of the electricity grid with its corresponding information systems view. The combined view that uses the information network to enhance the functioning of the electricity grid is generally what is called the smart grid.

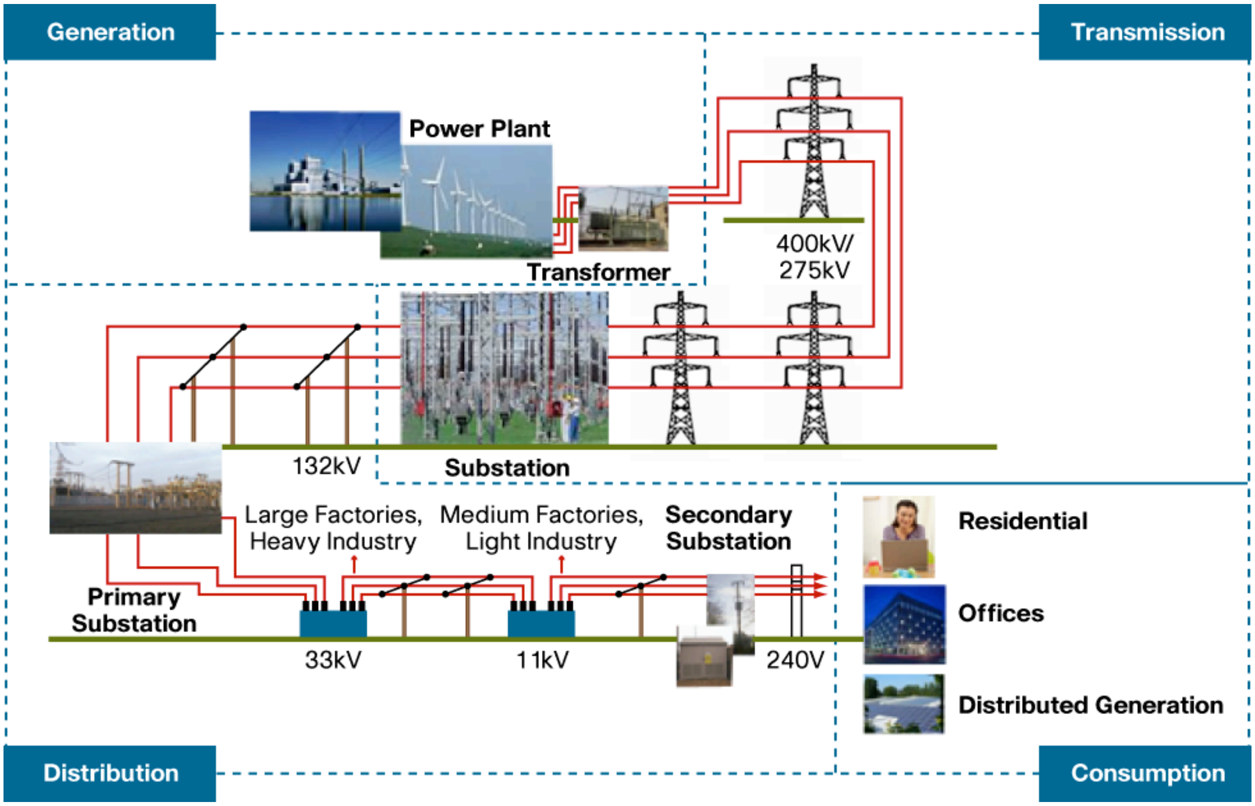
Power Systems View of the Electricity System

The power systems view of the electric grid describes the electric network in place for delivering electric power from its producers to its consumers (Figure 1). This network generally supports one of the following functions:

- **Power generation:** Power generation includes the facilities for generating power in central as well as distributed locations.
- **Electricity transmission:** Electricity transmission refers to the high-voltage network of electric cables used to take bulk power from generation facilities to power distributions facilities near populated areas.
- **Electricity distribution:** Electricity distribution is the process in which the high-voltage power is down-converted and disseminated to the consumers through a mesh network of cables reaching all the way to consumer premises.
- **Consumption:** Consumption refers to either a private or commercial entity that consumes power from the distribution network. The consumer may also participate in the generation and dissemination of power (such as through solar-generated power in homes).

In addition, electric trading markets also provide an overlay function that allows for purchase and sale of electric capacity.

Figure 1. Physical View of Power Infrastructure (Source: Cisco)



Information Systems View of the Electricity System

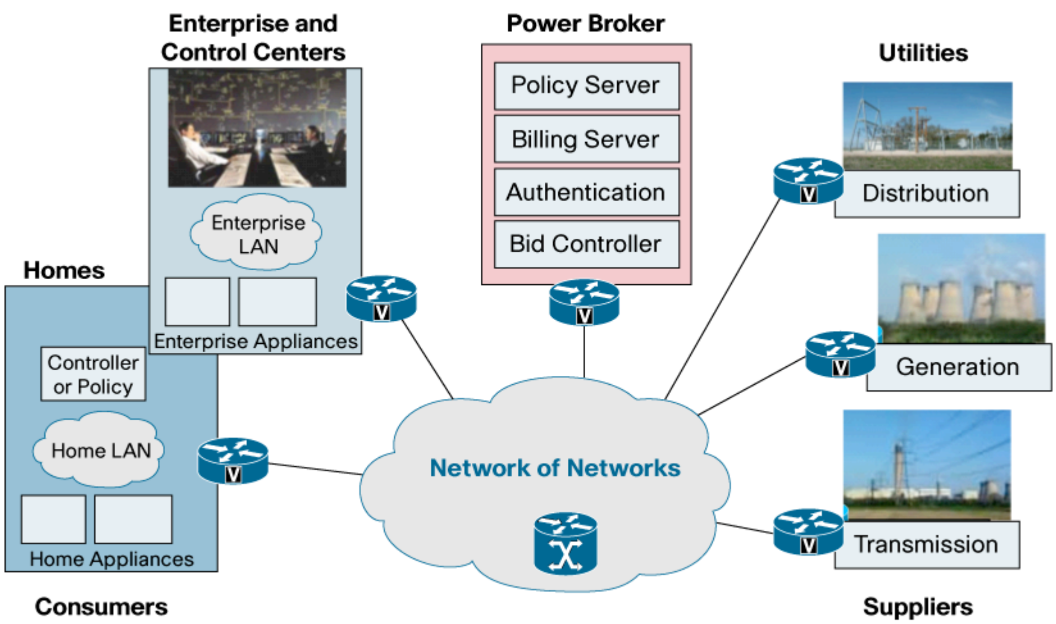
Operation of the electrical system today is possible through a series of sensors and devices that collect information from many different places in the system and pass it onto human and automatic operators (Figure 2). These operators make decisions based on this information about how to change the state of the system. These decisions are passed back to the grid where devices convert these decisions into actual changes on the electric grid.

Following are some of the sources of information on the grid:

- **Generation**
  - Equipment-conditioning information
  - Information from sensors monitoring the interconnections to the transmission grid
  - Overall load conditions of the generation equipment
- **Transmission**
  - Information from sensors monitoring the state of high-voltage power lines
  - Information from sensors monitoring the state of devices in the transmission substations
  - Information from phasor measurement units (PMUs) monitoring the state of the transmission grid
  - Information from workers maintaining the transmission lines
  - Information from environmental sensors around the transmission grid
  - Information from sensors monitoring the state of power lines
  - Information from sensors monitoring the state of devices in the distribution substations
  - Information from sensors monitoring the state of the feeders

  - Information from sensors measuring state and quality of power in the distribution network
  - Information from workers maintaining the distribution network
- **Consumer**
  - Overall power-usage information (meter reads)
  - Power-usage pattern information
  - Granular information about power usage by devices inside the home
  - Information from the distributed-generation sources in the home contributing information to the grid
  - Consumer electric-usage preference information (such as willingness to participate in load-reduction programs, etc.)

Figure 2. Information View of Power Infrastructure (Source: U.S. Patent 7,188,260 Apparatus and Method for Centralized Power Management)



Smart Grid: Integration of Power and Information Systems

Smart grid is the integration of power infrastructure with an information infrastructure, combining the maturity of the electric grid with the efficiency, connectivity, and cost gains brought about by Information Technology (IT). Smart grid would disrupt the way utilities do business. It would influence the way consumers consume energy and the way they interact with a utility. Ultimately, it would affect the nation's reliance on traditional energy sources.

Business Drivers for Smart Grid

Drivers for mart grid vary from one utility to the next, depending on the regulatory framework the utility falls under, the organizational structure of the utility, and the current state of the utility's grid operations among other things. However, at a high level, today utilities are concerned about the following priorities:

- Revenue generation, including regulatory compensation and lower total cost of ownership (TCO)
- Regulatory compliance
- Customer satisfaction and public image

Depending on how the utility is structured and the regulations that govern it, these three elements influence behaviors that are now moving utilities to embrace smart grid.

Revenue Generation, Including Regulatory Compensation

Two methods of revenue generation often used in U.S. utilities are affected by regulations either coupling or decoupling the utility's revenue from its sales volume. For utilities where the revenue is coupled to sales volume, there is significant incentive to ensure that the sales volumes do not drop, because a small percentage drop in sales volume causes a significant percentage drop in profitability. For utilities where revenue is decoupled from sales revenue, the throughput incentive (to keep sales volumes up) is diminished because the utility is allowed to compensate itself by charging customers more if the sales volume goes down. The decoupling structures are often supplemented by regulations that incentivize the utility to conserve electricity—and indeed get compensated for programs put in place to reduce electric consumption.

Irrespective of the type of revenue-generation mechanism a utility is governed by, smart grid allows the utility to meet its financial objectives more effectively through one or more of the following means:

- Not allowing its sales volume to drop below reference test year numbers
- Managing its costs at or around the test-year numbers (short-run costs are fairly static)
- Allowing it to earn incentive payment for any energy conservation plans that are in place
- Reducing costs through intelligent use of IT to help facilitate better communication between the different stakeholders shown in the traditional physical view, a process that also helps lower operational cost

Regulatory Compliance

Various types of regulations affect utilities, and adherence to them is a success requirement. The regulatory bodies develop these regulations to ensure that the utilities to provide the "cheapest, most reliable, ubiquitous, and cleanest" electricity for consumers. Following are some of the regulations that utilities in the United States must comply with:

- Regulations governing operations of the power plants a utility operates
- Regulations handed down by the Federal Electric Regulatory Commission (FECR) that control interstate transportation of electricity
- Rules laid out by state public utilities commissions (PUCs) governing rates, planning and spending practices, customer service, and operating policies
- Regulations handed down by the North American Electric Reliability Corporation (NERC)

Similar regulations are in place worldwide through various regulatory bodies, with considerable regional disparity in the definition but largely aligned to a similar set of business priorities.

All of these regulations affect behaviors, pushing the utilities to adopt aspects of the smart grid that allow them to comply effectively and efficiently with these regulations.

Customer Satisfaction and Public Image

Customer satisfaction and maintaining a positive public image are of paramount importance to utilities. Utilities work hard to predetermine potential causes of dissatisfaction, perform root-cause analyses of customer-satisfaction concerns, and generally expend great efforts to ensure long-term customer satisfaction. Two of the factors behind this follow:

- The utility's management and employees want the utility to be seen as responsible members of the society.
- Poor customer satisfaction can often lead to complaints being lodged with regulatory authorities who have control over rates of utilities in the United States, potentially making it difficult for a utility with a bad customer relationship record to continue to be allowed favorable rates of return.

Given these factors, utilities are keen to adopt smart grid measures that allow them to improve the satisfaction and experience of their customers with the electricity-consumption behavior.

In addition to the business factors, following are some of the challenges utilities face that have made them explore smart grid options more proactively:

- Load generated by electric vehicles
- Management of distributed generation
- Greater environmental mandates
- Aging power grid
- Rising fuel costs
- Rising construction costs

The intersection of the electrical grid and IT will certainly have its share of challenges. However, there is concerted agreement among regulatory bodies, utility companies, and other vendors that investing in smart grids is absolutely the right direction to pursue. Cisco actively subscribes to this vision.

Mapping Utility Business Drivers to Smart Grid Functions

Smart grid aligns very effectively with many of the business factors listed in the previous section. Table 1 examines some of the pains associated with achieving the goals for these business factors and correlates them with smart grid solutions that alleviate these pains.

Table 1. Smart Grid Solutions

Smart Grid Generation Solutions	
Generation Pain Points	**Smart Grid Solutions**
Poor asset conditioning and control	Integrated monitoring solutions and reduced grid losses by optimized asset usage
Distributed generation	Integration of various solutions to allow a distributed-generation environment to work, and decrement in future outages achieved by increasing share of renewables
Smart Grid Transmission Solutions	
Transmission Pain Points	**Smart Grid Solutions**
Line losses	Interconnected line-loss and voltage-control equipment
Theft	Physical security and electricity monitoring solutions
Inability to proactively diagnose problems	Integrated device monitoring solutions
Transmission system stress due to excessive load	Interconnections between distribution and transmission systems
NERC compliance concerns	Various types of solutions, depending on NERC regulation in question
Smart Grid Distribution Solutions	
Distribution Pain Points	**Smart Grid Solutions**
Inability to isolate faults	Integrated monitoring solutions, and real-time information about grid condition around each primary and secondary substation and pole-top transformer
Electricity theft	Integrated monitoring solutions
Copper theft	Physical security solutions (access control and video surveillance)
Liability concerns	Physical security solutions (access control and video surveillance)
NERC compliance concerns	Various types of solutions, depending on NERC regulation
Maintenance	Reduction in maintenance problems through integrated device health-monitoring solutions, and improved manageability by IP end-to-end communication
Lack of trained manpower for maintaining equipment	System automation, which allows utilities to use a smaller number of trained manpower
Distribution losses	Interconnected loss-reduction systems

Smart Grid Consumer Solutions	
Consumer Pain Points	**Smart Grid Solutions**
Lack of visibility into temporal electrical consumption for each customer	Advanced metering infrastructure (AMI)
Inability to exert direct control over customer electricity usage (demand response)	AMI: Demand-response solutions with direct load control
Poor diagnostics, resulting in power-restoration delays and outages	AMI plus Supervisory Control and Data Acquisition (SCADA) systems around the consumer premises
Cost of customer provisioning and de-provisioning	Demand-response solutions, and reduced cost by remote connects and disconnects
Lack of the consumer's' visibility into how they are consuming electricity (for usage reduction or optimization)	Home-energy-management (HEM) solutions
Inability to offer consumers value-added services	HEM, AMI plus future enhancements
Inability to offer customers green alternatives	An integrated end-to-end solution
Inability to use distributed generation to best advantage	Solutions to integrate distribution and generation assets
Outages	A collection of smart grid solutions ranging from demand-response solutions to better equipment monitoring
Expense of adding new customers	Improved field technician tools and service vehicles that allow faster integration
Lack of trained manpower for managing customers	System automation, which allows utilities to use a smaller number of trained manpower
Customer satisfaction concerns rooted in customer-response concerns	System automation, which allows early detection or even prevention of problems
Liability concerns	System monitoring solutions

Cisco's Intelligent Communications Infrastructure and Smart Grid

This section examines the pivotal role Cisco will play in the transformation of the utility industry. Cisco takes a systematic approach wherein Cisco analyzes the characteristics the grid of the future must have and how Cisco's intelligent network platform optimally enables these characteristics.

Intelligent Communications Infrastructure at the Core of Smart Grid

Table 2 describes how smart grid disrupts all departments in a utility and how an intelligent communications infrastructure is the critical factor for such disruption.

Table 2. Impact of Smart Grid on Utility Functions

Generation			
Primary Functions	**Description of Functions**	**How Smart Grid Affects These Functions**	**How an Intelligent Communications Infrastructure Enables and Amplifies the Smart Grid Impact**
Load control and dispatch	Economical load dispatch scheduling and optimization helps to select the right dispatch for the right load at the right time, reducing the cost of generation (startup, operations, and wind down).	Smart grid helps with the scheduling of the committed generating units so as to meet the required load demand at minimum operating cost while satisfying all units and system equality and inequality constraints.	Economic load dispatch during unforeseen events warrants robust real-time communication infrastructure between the demand and the generation functions.
Load shaping	Shaping the load during peak demand times reduces the idle and standby generation capacity.	Demand-side management (DSM) helps to manage and accurately estimate demand so as to meet demand without extra generation.	Load shaping with DSM involves reliable communication between AMI, (CIS (Consumer Information Systems)), and generation functions
Distributed, renewable generation	Integration of Microgrids as well as generation at customer premises with the utility infrastructure	Smart grid enables distributed generation and automated adjustment of feed-in tariff regulation to receive premiums in the case of forced switch-off of distributed-generation asset for balancing energy	Infrastructure is needed to confirm, analyze, and dispatch available load to distribution generation sources.
Generation equipment maintenance	Diagnoses and maintenance of the generation equipment reduces faults and prevents their propagation.	Smart grid helps asset management and conditioning in preventive maintenance. It also helps accessing newly sensed data.	Data from turbines needs to be transferred to the generation control center for better equipment conditioning and monitoring.

Transmission			
Primary Functions	**Description of Functions**	**How Smart Grid Affects These Functions**	**How an Intelligent Communications Infrastructure Enables and Amplifies the Smart Grid Impact**
Transmission-grid monitoring and control	Energy Management Systems (EMS) and transmission SCADA for data acquisition needed for the following functions: • Outage management • Volt/VAR management • State estimation • Network sensitivity analysis • Contingency analysis • Automatic generation control • Phasor data analysis	• Automated regulation of load tap changer and capacitor banks for voltage regulation. • Wide-area phasor measurement and control for grid optimization and control • Volt/VAR management using capacitor switches and controls	Substation automation results in two-way communication between transmission SCADA equipment and EMS. Communication between transmission and generation units is necessary for automatic generation control.
Maintenance of transmission control center	The transmission control center is the first layer of defense for transmission fault detection and prevention.	Automated operations eliminate human intervention in fault prevention, detection, isolation, and correction.	Real-time communication between primary and backup transmission control center, transmission, generation, and distribution units is necessary for control-center operations. Security technology deployment provides for secure data sharing between transmission and other utility functions.
Equipment maintenance	Maintenance of transmission equipment, including breakers, relays, switchers, transformers, and regulators, prevention of faults.	Smart grid helps asset management and conditioning for preventive maintenance.	Data from transmission equipment needs to be transferred to the generation control center for better equipment conditioning and monitoring.
Distribution			
Primary Operations	**Description of Operations**	**How Smart Grid Affects These Operations**	**How an Intelligent Communications Infrastructure Enables and Amplifies the Smart Grid Impact**
Feeder voltage regulation and phase balancing	Regulation of distribution voltage to prevent overcurrent problems. Maintain phase balance with the variation of customer load demand (unbalance will lead to equipment overloading and malfunction of protective relays).	Load consumption information from customer information systems will help in phase balancing. Information from distributed-generation assets will help with voltage regulation.	Distribution automation through low-cost Distributed Network Protocol 3 (DNP3) helps in monitoring and control. Communications between Distribution Management System (DMS) and distribution equipment is necessary for automated distribution operations.
Trouble call and dispatch	Analysis of distribution trouble-ticket analysis and dispatch to increase customer satisfaction.	Provisioning an automated outage notification and automated dispatch system. Equip mobile field force with data.	Real-time data, voice, and video into distribution trucks resulting in fewer trips and quicker restoration.
Planned and emergency switching	Automation of fault detection and correction at substations and feeders.	Automation of switching sequence for emergency switching.	Provides effective communications from the relay, breaker, and the feeders to the distribution control center
Power-quality maintenance	Maintain the right voltage levels across the distribution system.	Improvement of power quality by fast and effective use of information from devices that cause those events (transformers and motors).	Real-time communications from transformers and motors and power analytics systems is necessary for power-quality maintenance.

Energy Trading, Consumers, and Others				
Other Utility Functions	**Primary Operations**	**Description of Operations**	**How Smart Grid Affects These Functions**	**How an Intelligent Communications Infrastructure Enables and Amplifies the Smart Grid Impact**
Energy trading	Forecasting Market modeling Demand-response programs Risk management	Energy trading enables a utility to buy energy to meet peak demand or to sell excess capacity.	Smart grid provides real-time demand and generation information for energy-trading decisions.	Real-time communications between analytics, demand, and generation units is necessary for effective decision making regarding energy trading.
Consumer	Home energy management	HEM helps users to monitor and control the time, amount, type, and level of energy usage.	HEM data can ride on the neighborhood area network when smart grid is employed.	Low-cost backhaul communications methods are necessary for HEM traffic.
	Metering	Meter data is used for billing purposes.	Advanced Metering Infrastructure (AMI) allows for remote meter reads, connects and disconnects an automated outage detection.	Scalable, reliable, low-cost backhaul communications methods are necessary for AMI traffic.
	Demand-side management	Management of demand-side load.	Smart Grid enables sophisticated demand side managed by integrating HEM, AMI data with demand response techniques.	DSM needs communications between HEM equipment, AMI, and generation units.
Intergrid communications	Communication between regional coordinators	Coordination is needed for better information flow between grids for fault isolation and prevention of fault cascading.	Smart grid enables communication of real-time data between regional control centers.	Secure communications are needed for ICCP (Inter-Control Center Protocol) infrastructure.

Core Infrastructure			
Primary Functions	**Description of Functions**	**How Smart Grid Affects These Functions**	**How an Intelligent Communications Infrastructure Enables and Amplifies the Smart Grid Impact**
Preparing, planning, and designing a network to support a common, converged infrastructure that supports all functions of a utility with support for smart grid	Smart grid requires communications between all functions of a utility, namely generation, transmission, distribution, consumer, and energy trading. A highly available common communications infrastructure is therefore necessary.	Smart grid can increase the return on investment (ROI) if all the utility functions use a common converged infrastructure with all the advanced technologies, including: • Unified communications (data, voice, and video collaboration) • Physical security • Management tools	A secure, scalable, resilient, and manageable Future Proof network that will be compatible with future versions is a necessity for the core infrastructure that supports all smart grid functions. Selecting technologies that are common across utility functions will help in the manageability of operations. The result will be reduced operating expenses (OpEx) to operate the communication system because the network is IP from end to end.

Cisco's Vision for Smart Grid

Cisco is the world leader in the design and implementation of end-to-end converged intelligent communication infrastructures. It has a proven track record of helping industries through transitions and possess considerable expertise in converged networks: data, voice, and now video. Cisco's products deployed at various places in the network are proven. The Cisco IOS® Software Operating System has formed the backbone of the Internet and has withstood against attacks. Cisco's secure architectures and rich feature sets support comprehensive security, resiliency, and manageability. Cisco firmly believes in open standards and interoperability—crucial features to meet the needs of any large-scale infrastructure deployment now and in the future.

Cisco optimally enables the smart grid vision through the core infrastructure design for interoperable communications between Smart Grid components. As described in the previous sections, smart grid requires transparent information flow between transmission, distribution, generation, home, and other communication networks such as the corporate network and the networks used for energy trading.

This section describes Cisco's vision of the smart grid and how it will make this vision become a reality.

- **Secure, resilient, and self-healing:** Cisco's vision is to build a smart grid of the future that is highly secure, resilient, and self-healing. The worldwide Internet is perhaps the best example of a large-scale environment that is truly resistant to a large variety of attacks and can heal itself. Cisco has been the primary enabler of the Internet and connected networks, and has developed both product and service expertise that allows Cisco to help its customers and partners build large-scale communications environments that can withstand errors, flaws, and attacks. In addition, the Cisco® Self-Defending Network philosophy integrates security throughout the network, allowing attacks to be thwarted expeditiously and effectively. These are some of the reasons Cisco is uniquely positioned to build a smart grid of the future that can be highly secure, resilient, and self-healing.

  A few examples of how Cisco's IP expertise and breadth of networking products and solutions will help weave these components into the fabric of the smart grid follow:

  - Introducing networking equipment and software with built-in and interconnected security
  - Leveraging time-tested routing techniques to best advantage to ensure resilience and self-healing
  - Providing protocol and device hardening tools and techniques
  - Segmenting devices, networks, and functions of a smart grid
  - Providing secure access control of devices and users into the smart grid
  - Integrating monitoring and analysis for detecting problems

- **Efficient and effective operations:** Cisco believes that the optimal smart grid functions can be achieved by building it on top of a communications infrastructure that can carry a wide variety of traffic while effectively providing the appropriate handling for each type. A fully and properly connected environment with suitable mechanisms for sharing information allows resources to be recognized and used in the most effective manner. Focus areas include increased manageability and smooth policy enforcement. Cisco's vision is for transparent integration of unified communications (voice, video, etc.) and advanced technologies (physical security, storage, etc.) in a best-of-class network that truly brings about the smart grid transformation.
- **Ubiquitous reach and inclusiveness:** Cisco's vision is one of open and ubiquitous communications between all the entities legitimately connected to the smart grid, implying that all the departments within a utility must work together to ensure the build-out of an environment that most efficiently meets their needs. In addition, Cisco has promoted protocols over the years that, through standardization at the IETF, the IEEE, and other standards bodies and widespread deployment, have allowed the new information age to emerge without any barriers. Cisco has this vision for smart grid also—a smart grid where ubiquitous access to power-related information and inclusiveness is the norm.
- **Open and manageable:** Cisco's vision for the smart grid is that of an environment that, although very large and complex, comprises protocols that are known and an infrastructure that is easily managed.
- **Services:** Cisco believes in a smart grid that comprises solutions that meet the overall objectives of smart grid programs. It believes that a smart grid environment can be best developed and optimally maintained through a healthy trust-based relationship between Cisco and its utility customers. Cisco believes in providing its customers with an array of superior services, from planning and business case analysis to operating and optimizing the environment.

- **Business factors:** Cisco believes that the true potential of the smart grid lies in its development, which results from well-researched business goals and objectives of the utilities. It is committed to working with utilities in determining the business case and ROI for deployment of smart grid functions for their unique environments, and then partnering with them to help ensure that the development and deployment of the smart grid infrastructure remains in line with these goals.
- **An ecosystem of partners:** Cisco's vision is for a smart grid for the future that is built through an ecosystem of partners, each bringing its unique skills and capabilities to garner the most of the smart grid concept. Cisco believes in creating an open environment of trust and collaboration where the goals and interest of the customer are of foremost importance at all times.

Conclusion

Cisco's vision is to help create a resilient, self-healing, highly secure, and inclusive grid environment that optimally combines all the disparate sources of information in the utility environment. This scenario would allow for effective decisions to be made and timely actions propagated to the most relevant actuation points, resulting in the smart grid benefits that the utility and its consumers want.

Cisco believes that it can generate great value for Cisco's utility customers through a well-developed strategy for achieving the greatest value with a smart grid. This strategy is rooted in a business goals-directed approach to the development of a smart grid in the utility environment. Cisco is well-known for bringing productivity transformation to entire industries through its unique yet interconnected array of information technologies. The time is right for Cisco and the utilities to come together and introduce a new era in electricity generation, distribution, and consumption.

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For More Information

For more information about smart grid, please visit: www.cisco.com/go/smartgrid

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Singapore

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