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A **smart grid** delivers electricity from suppliers to consumers using two-way digital technology to control appliances at consumers' homes to save energy, reduce cost and increase reliability and transparency. Such a modernized electricity network is being promoted by many governments as a way of addressing energy independence, global warming and emergency resilience issues. Smart meters may be part of a smart grid, but alone do not constitute a smart grid.

A smart grid includes an intelligent monitoring system that keeps track of all electricity flowing in the system. It also incorporates the use of superconductive transmission lines for less power loss, as well as the capability of integrating alternative sources of electricity such as solar and wind. When power is least expensive a smart grid could turn on selected home appliances such as washing machines or factory processes that can run at arbitrary hours. At peak times it could turn off selected appliances to reduce demand.

Similar proposals include *smart electric grid*, *smart power grid*, *intelligent grid* (or *intelligrid*), *FutureGrid*, and the more modern *intergrid* and *intragrid*.

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Goals

In principle, the smart grid is a simple upgrade of 20th century power grids that generally "broadcast" power from a few central power generators to a large number of users, to instead be capable of routing power in more optimal ways to respond to a very wide range of conditions, and to charge a premium to those that use energy at peak hours.

Respond to many conditions in supply and demand

The conditions to which a smart grid, broadly stated, could respond, occur anywhere in the power generation, distribution and demand chain. Events may occur generally in the environment (clouds blocking the sun and reducing the amount of solar power, a very hot day), commercially in the power supply market (prices to meet a high peak demand), locally on the distribution grid (MV transformer failure requiring a temporary shutdown of one distribution line) or in the home (someone leaving for work, putting various devices into hibernation, data ceasing to flow to an IPTV) that motivate a change to power flow.

Latency of the data flow is a major concern, with some early smart meter architectures allowing actually as long as 24 hours delay in receiving the data, preventing any possible reaction by either supplying or demanding devices.[1]

Provision megabits, control power with kilobits, sell the rest

The amount of data required to perform monitoring and switching your appliances off without your consent is very small compared with that already reaching even remote homes to support voice, security, Internet and TV services. Many smart grid bandwidth upgrades are paid for by over-provisioning to support also consumer services, and subsidizing the communications with energy-related services or subsidizing the energy-related services, such as higher rates during peak hours, with communications. This is particularly true where governments run both sets of services as a public monopoly, e.g. in India. Because power and communications companies are generally separate commercial enterprises in North America and Europe, it has required considerable government and large-vendor effort to encourage various enterprises to cooperate. Some, like Cisco, see opportunity in providing devices to consumers very similar to those they have long been providing to industry.[2] Others , such as Silver Spring Networks[3] or Google[4][5], are data integrators rather than vendors of equipment. While the AC power control standards suggest powerline networking would be the primary means of communication among smart grid and home devices, the bits may not reach the home via BPL initially but by fixed wireless. This may be only an interim solution however as separate power and data connections simply defeats full control.

Scale and scope

Europe's SuperSmart Grid, as well as earlier proposals (such as Al Gore's continental Unified Smart Grid) make semantic distinctions between local and national grids that sometimes conflict.

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Papers [6] by Battaglini et al. associate the term "smart grid" with local clusters (page 6), whereas the intelligent interconnecting backbone provides an additional layer of coordination above the local smart grids. Media use in both Europe and the US however tends to conflict national and local.

Regardless of terminology used, smart grid projects always intend to allow the continental and national interconnection backbones to fail without causing local smart grids to fail. They would have to be able to function independently and ration whatever power is available to critical needs.

Municipal grid

Before recent standards efforts, municipal governments, for example in Miami, Florida[7], have historically taken the lead in enforcing integration standards for smart grids/meters. As municipalities or municipal electricity monopolies also often own some fiber optic backbones and control transit exchanges at which communication service providers meet, they are often well positioned to force good integration.

Municipalities also have primary responsibility for emergency response and resilience, and would in most cases have the legal mandate to ration or provision power, say to ensure that hospitals and fire response and shelters have priority and receive whatever power is still available in a general outage.

Home Area Network

A Home Area Network, or "home grid", extends some of these capabilities into the home using powerline networking and/or RF using standards such as Zigbee, INSTEON, Zwave, or others.

Because of the communication standards both smart power grids and some Home Area Networks support more bandwidth than is required for power control and therefore may cost more than required. The existing 802.11 home networks generally have megabits of additional bandwidth for other services (burglary, fire, medical and environmental sensors and alarms, ULC and CCTV monitoring, access control and keying systems, intercoms and secure phone line services), and accordingly can't be separated from LAN and VoIP networking, nor from TV once the IPTV standards have emerged.

Consumer electronics devices now consume over half the power in a typical US home. Accordingly, the ability to shut down or hibernate devices when they are not receiving data could be a major factor in cutting energy use, but this would mean the electric company has information on whether you are using your computer or not, and if, for example, you simply have a screen saver on with family pictures while you do chores or work around the house, the electric company could at their discretion decide your computer is not being used and turn it off for you.

Other key devices that could aide in the utilities efforts to shed load during times of peak demand include air conditioning units, electric water heaters, pool pumps and other high wattage devices. In 2009, smart grid companies may represent one of the biggest and fastest growing sectors in the "cleantech" market [8]. It consistently receives more than half the venture capital investment.

In 2009 President Barack Obama asked the United States Congress "to act without delay" to pass legislation that included doubling alternative energy production in the next three years and building a new electricity "**smart grid**". [9] On April 13, 2009, George W. Arnold was named the first National Coordinator for Smart Grid Interoperability [10]. In June 2009, the NIST announced a smart grid interoperability project via IEEE P2030[11].

Europe and Australia are also following similar visions. In those parts of the world, the integration of communications and power control, both of which have generally fallen under more government supervision, is more advanced, with utilities often required or asked to provide competitive access to communications transit exchanges and distributed power co-generation connection points.

On August 20, 2009, Casa Presedencial in Costa Rica introduced a bill to the country's Legislative Assembly that would open up the energy market that is currently run by a government monopoly, and require all new private electricity generators to use smart grid technology.

Researchers and regulators support IP, closer power and data ties

Bill St. Arnaud of CANARIE (Canada's backbone research institute) argues often for closer integration of power and telecom policy, proposing that consumers should own their own power meter data explicitly and that they should have a choice of service providers for communication and power management, with reach potentially into every home AC outlet. [12] In the US, FCC Chair Michael Powell likewise expresses support for this principle of unifying the power management and other data services and offering basic levels of both to every consumer, rather than allowing power management to exist in its own separate "silo" or be confined only to non-IP-based meters or devices.

The IEEE P2030 project seeks to define interoperability between various types of power grids, in part to prevent the emergence of too many incompatible silos that would cause the overall grid to be less resilient.

What a smart grid is

The function of an Electrical grid is not a single entity but an aggregate of multiple networks and multiple power generation companies with multiple operators employing varying levels of communication and coordination, most of which is manually controlled. Smart grids increase the connectivity, automation and coordination between these suppliers, consumers and networks that perform either long distance transmission or local distribution tasks.

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- Transmission networks move electricity in bulk over medium to long distances, are actively managed, and generally operate from 345kV to 800kV over AC and DC lines.
- Local networks traditionally moved power in one direction, "distributing" the bulk power to consumers and businesses via lines operating at 132kV and lower.

This paradigm is changing as businesses and homes begin generating more wind and solar electricity, enabling them to sell surplus energy back to their utilities. Modernization is necessary for energy consumption efficiency, real time management of power flows and to provide the bi-directional metering needed to compensate local producers of power. Although transmission networks are already controlled in real time, many in the US and European countries are antiquated[13] by world standards, and unable to handle modern challenges such as those posed by the intermittent nature of alternative electricity generation, or continental scale bulk energy transmission.

Modernizes both transmission and distribution

A smart grid is an umbrella term that covers modernization of both the transmission and distribution grids. The modernization is directed at a disparate set of goals including facilitating greater competition between providers, enabling greater use of variable energy sources, establishing the automation and monitoring capabilities needed for bulk transmission at cross continent distances, and enabling the use of market forces to drive energy conservation.

Many smart grid features readily apparent to consumers such as smart meters serve the energy efficiency goal. The approach is to make it possible for energy suppliers to charge variable electric rates so that charges would reflect the large differences in cost of generating electricity during peak or off peak periods. Such capabilities allow load control switches to control large energy consuming devices such as hot water heaters so that they consume electricity when it is cheaper to produce.

Peak curtailment/levelling and time of use pricing

To reduce demand during the high cost peak usage periods, communications and metering technologies inform smart devices in the home and business when energy demand is high and track how much electricity is used and when it is used. To motivate them to cut back use and perform what is called **peak curtailment** or **peak levelling**, prices of electricity are increased during high demand periods, and decreased during low demand periods. It is thought that consumers and businesses will tend to consume less during high demand periods if it is possible for consumers and consumer devices to be aware of the high price premium for using electricity at peak periods, this could mean cooking dinner at 9pm instead of 5pm. When businesses and consumers see a direct economic benefit of not having to pay double for the same energy use to become more energy efficient, the theory is that they will include energy cost of operation into their consumer device and building construction decisions. *See Time of day metering and demand response*.

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According to proponents of smart grid plans,[who?] this will reduce the amount of spinning reserve that electric utilities have to keep on stand-by, as the load curve will level itself through a combination of "invisible hand" free-market capitalism and central control of a large number of devices by power management services that pay consumers a portion of the peak power saved by turning their devices off.

Essential for renewable energy

Supporters of renewable energy favor smarter grids, because most renewable energy sources are intermittent in nature, depending on natural phenomena (the sun and the wind) to generate power. Thus, any type of power infrastructure using a significant portion of intermittent renewable energy resources must have means of effectively reducing electrical demand by "load shedding" in the event that the natural phenomena necessary to generate power do not occur. By increasing electricity prices exactly when the desired natural phenomena are not present, consumers will, in theory, decrease consumption. However this means prices are unpredictable and literally vary with the weather, at least to the distribution utility.

Platform for advanced services

As with other industries, use of robust two-way communications, advanced sensors, and distributed computing technology will improve the efficiency, reliability and safety of power delivery and use. It also opens up the potential for entirely new services or improvements on existing ones, such as fire monitoring and alarms that can shut off power, make phone calls to emergency services and etc..

US and UK savings estimates and assumptions behind them

One United States Department of Energy study calculated that internal modernization of US grids with smart grid capabilities would save between 46 and 117 billion dollars over the next 20 years[14]. As well as these industrial modernization benefits, smart grid features could expand energy efficiency beyond the grid into the home by coordinating low priority home devices such as water heaters so that their use of power takes advantage of the most desirable energy sources. Smart grids can also coordinate the production of power from large numbers of small power producers such as owners of rooftop solar panels — an arrangement that would otherwise prove problematic for power systems operators at local utilities.

The above vision makes two assumptions. First, that they will act in response to market signals and there needs to be some sort of telecommunications network. In the UK, where consumers have for nearly 10 years had a choice in the company from which they purchase electricity, more than 80% have stayed with their existing supplier, despite the fact that there are significant differences in the prices offered by a given electricity supplier. End users may be less responsive to price signals than proponents of Smart Grids think. Second, in the case of the telecomms aspect of Smart Grids, this ignores the possibility of bringing autonomy to a given appliance. Various companies (such as RLTec) have developed low cost systems that allow products to react to network fluctuations (usually network frequency). This type of control is called "dynamic demand management". A feature of DDM being that, it is low cost, needs no telecomms network and is available now. Of course these are not points that proponents of a "power telecomms network" may wish to hear about or indeed see propagated.

Although there are specific and proven smart grid technologies in use, *smart grid* is an aggregate term for a set of related technologies on which a specification is generally agreed, rather than a name for a specific technology. Some of the benefits of such a modernized electricity network include the ability to reduce power consumption at the consumer side during peak hours, called Demand side management; enabling grid connection of distributed generation power (with photovoltaic arrays, small wind turbines, micro hydro, or even combined heat power generators in buildings); incorporating grid energy storage for distributed generation load balancing; and eliminating or containing failures such as widespread power grid cascading failures. The increased efficiency and reliability of the smart grid is expected to save consumers money and help reduce CO_2 emissions.

History

Today's alternating current power grid evolved after 1896, based in part on Nikola Tesla's design published in 1888 (see War of Currents). Many implementation decisions that are still in use today were made for the first time using the limited emerging technology available 120 years ago. Specific obsolete power grid assumptions and features (like centralized unidirectional[1] electric power transmission, electricity distribution, and demand-driven control) represent a vision of what was thought possible in the 19th century.

Part of this is due to an institutional risk aversion that utilities naturally feel regarding use of untested technologies on a critical infrastructure they have been charged with defending against any failure, however momentary.[citation needed]

Over the past 50 years, electricity networks have not kept pace with modern challenges, such as:

- security threats, from either energy suppliers or cyber attack
- national goals to employ alternative power generation sources whose intermittent supply makes maintaining stable power significantly more complex
- conservation goals that seek to lessen peak demand surges during the day so that less energy is wasted in order to ensure adequate reserves
- high demand for an electricity supply that is un-interruptible
- digitally controlled devices that can alter the nature of the electrical load (giving the electric company the ability to turn off appliances in your home if they see fit) and result in electricity demand that is incompatible with a power system that was built to serve an "analog economy." For a simple example, timed Christmas lights can present significant surges in demand because they come on at near the same time (sundown or a set time).[citation needed] Without the kind of coordination that a smart grid can provide, the increased use of such devices lead to electric service reliability problems, power quality disturbances, blackouts, and brownouts [15].

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Although these points tend to be the "conventional wisdom" with respect to smart grids, their relative importance is debatable. For instance, despite the weaknesses of power network being publicly broadcast, there has never been an attack on a power network in the United States or Europe.[citation needed] However, in April 2009 it was learned that spies had infiltrated the power grids, perhaps as a means to attack the grid at a later time.[citation needed] In the case of renewable power and its variability, recent work undertaken in Europe (Dr. Bart Ummels et al.)[Full citation needed] suggests that a given power network can take up to 30% renewables (such as wind and solar) without any changes whatsoever.

The term smart grid has been in use since at least 2005, when the article "Toward A Smart Grid", authored by S. Massoud Amin and Bruce F. Wollenberg appeared in the September/October issue of *IEEE P&E Magazine* (Vol. 3, No.3, pgs 34-41). The term had been used previously and may date as far back as 1998. There are a great many smart grid definitions, some functional, some technological, and some benefits-oriented. A common element to most definitions is the application of digital processing and communications to the power grid, making data flow and information management central to the smart grid. Various capabilities result from the deeply integrated use of digital technology with power grids, and integration of the new grid information flows into utility processes and systems is one of the key issues in the design of smart grids. Electric utilities now find themselves making three classes of transformations: improvement of infrastructure, called the *strong grid* in China; addition of the digital layer that is the essence of the *smart grid*; and business process transformation, necessary to capitalize on the investments in smart technology. Much of the modernization work that has been going on in electric grid modernization, especially substation and distribution automation, is now included in the general concept of the smart grid, but additional capabilities are evolving as well.

Smart grid technologies have emerged from earlier attempts at using electronic control, metering, and monitoring. In the 1980s, Automatic meter reading was used for monitoring loads from large customers, and evolved into the Advanced Metering Infrastructure of the 1990s, whose meters could store how electricity was used at different times of the day.[16] Smart meters add continuous communications so that monitoring can be done in real time, and can be used as a gateway to demand response-aware devices and "smart sockets" in the home. Early forms of such Demand side management technologies were dynamic demand aware devices that passively sensed the load on the grid by monitoring changes in the power supply frequency. Devices such as industrial and domestic air conditioners, refrigerators and heaters adjusted their duty cycle to avoid activation during times the grid was suffering a peak condition. Beginning in 2000, Italy's Telegestore Project was the first to network large numbers (27 million) of homes using such smart meters connected via low bandwidth power line communication[17]. Recent projects use Broadband over Power Line (BPL) communications, or wireless technologies such as mesh networking that is advocated as providing more reliable connections to disparate devices in the home as well as supporting metering of other utilities such as gas and water[citation needed].

Monitoring and synchronization of wide area networks were revolutionized the early 1990s when the Bonneville Power Administration expanded its smart grid research with prototype sensors that are capable of very rapid analysis of anomalies in electricity quality over very large geographic areas. The culmination of this work was the first operational Wide Area

Measurement System (WAMS) in 2000[18]. Other countries are rapidly integrating this technology — China will have a comprehensive national WAMS system when its current 5-year economic plan is complete in 2012[19].

First cities with smart grids

The earliest, and still largest, example of a smart grid is the Italian system installed by Enel S.p.A. of Italy. Completed in 2005, the Telegestore project was highly unusual in the utility world because the company designed and manufactured their own meters, acted as their own system integrator, and developed their own system software. The Telegestore project is widely regarded as the first commercial scale use of smart grid technology to the home, and delivers annual savings of 500 million € at a project cost of 2.1 billion €.[17].

In the US, the city of Austin, Texas has been working on building its smart grid since 2003, when its utility first replaced 1/3 of its manual meters with smart meters that communicate via a wireless mesh network. It currently manages 200,000 devices real-time (smart meters, smart thermostats, and sensors across its service area), and expects to be supporting 500,000 devices real-time in 2009 servicing 1 million consumers and 43,000 businesses[20]. Boulder, Colorado completed the first phase of its smart grid project in August 2008. Both systems use the smart meter as a gateway to the home automation network (HAN) that controls smart sockets and devices. Some HAN designers favor decoupling control functions from the meter, out of concern of future mismatches with new standards and technologies available from the fast moving business segment of home electronic devices[21].

Hydro One, in Ontario, Canada is in the midst of a large-scale Smart Grid initiative, deploying a standards-compliant communications infrastructure from Trilliant. By the end of 2010, the system will serve 1.3 million customers in the province of Ontario. The initiative won the "Best AMR Initiative in North America" award from the Utility Planning Network. [22]

Problem definition

The major driving forces to modernize current power grids can be divided in four, general categories.

- Increasing reliability, efficiency and safety of the power grid.
- Enabling decentralized power generation so homes can be both an energy client and supplier (provide consumers with interactive tool to manage energy usage).
- Flexibility of power consumption at the clients side to allow supplier selection (enables distributed generation, solar, wind, biomass).
- Increase GDP by creating more new, green-collar energy jobs related to renewable energy industry manufacturing, plug-in electric vehicles, solar panel and wind turbine generation, energy conservation construction[23][24].

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Smart grid functions

Before examining particular technologies, a proposal can be understood in terms of what it is being required to do. The governments and utilities funding development of grid modernization have defined the functions required for smart grids. According to the United States Department of Energy's Modern Grid Initiative report[24], a modern smart grid must:

1. Be able to heal itself
2. Motivate consumers to actively participate in operations of the grid
3. Resist attack
4. Provide higher quality power that will save money wasted from outages
5. Accommodate all generation and storage options
6. Enable electricity markets to flourish
7. Run more efficiently
8. Enable higher penetration of intermittent power generation sources

Self-healing

Using real-time information from embedded sensors and automated controls to anticipate, detect, and respond to system problems, a smart grid can automatically avoid or mitigate power outages, power quality problems, and service disruptions.[*citation needed*]

As applied to distribution networks, there is no such thing as a "self healing" network. If there is a failure of an overhead power line, given that these tend to operate on a radial basis (for the most part) there is an inevitable loss of power. In the case of urban/city networks that for the most part are fed using underground cables, networks can be designed (through the use of interconnected topologies) such that failure of one part of the network will result in no loss of supply to end users. A fine example of an interconnected network using zoned protection is that of the Merseyside and North Wales Electricity Board (MANWEB).

It is envisioned that the smart grid will likely have a control system that analyzes its performance using distributed, autonomous reinforcement learning controllers that have learned successful strategies to govern the behavior of the grid in the face of an ever changing environment such as equipment failures. Such a system might be used to control electronic switches that are tied to multiple substations with varying costs of generation and reliability.[25]

Consumer participation

A smart grid, is, in essence, an attempt to require consumers to change their behavior around variable electric rates or to pay vastly increased rates for the privilege of reliable electrical service during high-demand conditions. Historically, the intelligence of the grid in North America has been demonstrated by the utilities operating it in the spirit of public service and shared responsibility, ensuring constant availability of electricity at a constant price, day in and day out, in the face of any and all hazards and changing conditions. A smart grid incorporates consumer equipment and behavior in grid design, operation, and communication. This enables consumers to better control (or be controlled by) “smart appliances” and “intelligent equipment” in homes and businesses, interconnecting energy management systems in “smart buildings” and enabling consumers to better manage energy use and reduce energy costs. Advanced communications capabilities equip customers with tools to exploit real-time electricity pricing, incentive-based load reduction signals, or emergency load reduction signals.

There is marketing evidence of consumer demand for greater choice. A survey conducted in the summer of 2007 interviewed almost 100 utility executives and sought the opinions of 1,900 households and small businesses from the U.S., Germany, Netherlands, England, Japan and Australia[26]. Among the findings:

1. 83% of those who cannot yet choose their utility provider would welcome that option
2. Roughly two-thirds of the customers that do not yet have renewable power options would like the choice
3. Almost two-thirds are interested in operating their own generation, provided they can sell power back to the utility

And as already noted, in the UK where the experiment has been running longest, 80% have no interest in change (source: National Grid).

The real-time, two-way communications available in a smart grid will enable consumers to be compensated for their efforts to save energy and to sell energy back to the grid through net-metering. By enabling distributed generation resources like residential solar panels, small wind and plug-in hybrid, smart grid will spark a revolution in the energy industry by allowing small players like individual homes and small businesses to sell power to their neighbors or back to the grid. The same will hold true for larger commercial businesses that have renewable or back-up power systems that can provide power for a price during peak demand events, typically in the summer when air condition units place a strain on the grid. This participation by smaller entities has been called the "democratization of energy"[*citation needed*]—it is similar to former Vice President Al Gore's vision for a Unified Smart Grid.

Resist attack

Smart grid technologies better identify and respond to man-made or natural disruptions. Real-time information enables grid operators to isolate affected areas and redirect power flows around damaged facilities.

One of the most important issues of resist attack is the smart monitoring of power grids that is the basis of control and management of smart grids to avoid or mitigate the system-wide disruptions like blackouts. The traditional monitoring is based on weighted least square (WLS) that is very weak and prone to fail when gross errors (including topology errors, measurement errors or parameter errors) are present. New technology of state monitor is needed to achieve the goals of the smart grids.

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High quality power

Outages and power quality issues cost US businesses more than $100 billion on average each year[27]. It is asserted that assuring more stable power provided by smart grid technologies will reduce downtime and prevent such high losses.

Accommodate generation options

As smart grids continue to support traditional power loads they also seamlessly interconnect fuel cells, renewables, microturbines, and other distributed generation technologies at local and regional levels. Integration of small-scale, localized, or on-site power generation allows residential, commercial, and industrial customers to self-generate and sell excess power to the grid with minimal technical or regulatory barriers. This also improves reliability and power quality, reduces electricity costs, and offers more customer choice.

Enable electricity market

Significant increases in bulk transmission capacity will require improvements in transmission grid management. Such improvements are aimed at creating an open marketplace where alternative energy sources from geographically distant locations can easily be sold to customers wherever they are located.

Intelligence in distribution grids will enable small producers to generate and sell electricity at the local level using alternative sources such as rooftop-mounted photo voltaic panels, small-scale wind turbines, and micro hydro generators. Without the additional intelligence provided by sensors and software designed to react instantaneously to imbalances caused by intermittent sources, such distributed generation can degrade system quality.

Optimize assets

A smart grid can optimize capital assets while minimizing operations and maintenance costs. Optimized power flows reduce waste and maximize use of lowest-cost generation resources. Harmonizing local distribution with interregional energy flows and transmission traffic improves use of existing grid assets and reduces grid congestion and bottlenecks that can ultimately produce consumer savings.

Enable high penetration of intermittent generation sources

Climate change and environmental concerns will increase the amount of renewable energy resources. These are for the most part intermittent in nature. Smart Grid technologies will enable power systems to operate with larger amounts of such energy resources since they enable both the suppliers and consumers to compensate for such intermittency.

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Features

Existing and planned implementations of smart grids provide a wide range of features to perform the required functions.

Load adjustment

The total load connected to the power grid can vary significantly over time. Although the total load is the sum of many individual choices of the clients, the overall load is not a stable, slow varying, average power consumption. Imagine the increment of the load if a popular television program starts and millions of televisions will draw current instantly. Traditionally, to respond to a rapid increase in power consumption, faster than the start-up time of a large generator, some spare generators are put on a dissipative standby mode[*citation needed*]. A smart grid may warn all individual television sets, or another larger customer, to reduce the load temporarily (to allow time to start up a larger generator) or continuously (in the case of limited resources). Using mathematical prediction algorithms it is possible to predict how many standby generators need to be used, to reach a certain failure rate. In the traditional grid, the failure rate can only be reduced at the cost of more standby generators. In a smart grid, the load reduction by even a small portion of the clients may eliminate the problem.

Demand response support

Demand response support allows generators and loads to interact in an automated fashion in real time, coordinating demand to flatten spikes. Eliminating the fraction of demand that occurs in these spikes eliminates the cost of adding reserve generators, cuts wear and tear and extends the life of equipment, and allows users to cut their energy bills by telling low priority devices to use energy only when it is cheapest[28].

Currently, power grid systems have varying degrees of communication within control systems for their high value assets, such as in generating plants, transmission lines, substations and major energy users. In general information flows one way, from the users and the loads they control back to the utilities. The utilities attempt to meet the demand and succeed or fail to varying degrees (brownout, rolling blackout, uncontrolled blackout). The total amount of power demand by the users can have a very wide probability distribution that requires spare generating plants in standby mode to respond to the rapidly changing power usage. This one-way flow of information is expensive; the last 10% of generating capacity may be required as little as 1% of the time, and brownouts and outages can be costly to consumers.

Greater resilience to loading

Although multiple routes are touted as a feature of the smart grid, the old grid also featured multiple routes. Initial power lines in the grid were built using a radial model, later connectivity was guaranteed via multiple routes, referred to as a network structure. However, this created a new problem: if the current flow or related effects across the network exceed the limits of any particular network element, it could fail, and the current would be shunted to other network elements that eventually may fail also, causing a domino effect. See power outage. A technique to prevent this is load shedding by rolling blackout or voltage reduction (brownout).[citation needed]

Decentralization of power generation

Another element of fault tolerance of smart grids is decentralized power generation. Distributed generation allows individual consumers to generate power onsite, using whatever generation method they find appropriate. This allows individual loads to tailor their generation directly to their load, making them independent from grid power failures. Classic grids were designed for one-way flow of electricity, but if a local sub-network generates more power than it is consuming, the reverse flow can raise safety and reliability issues. A smart grid can manage these situations.[citation needed]

Price signaling to consumers

In many countries, including Belgium, the Netherlands and the UK, the electric utilities have installed double tariff electricity meters in many homes to encourage people to use their electric power during night time or weekends, when the overall demand from industry is very low. During off-peak time the price is reduced significantly, primarily for heating storage radiators or heat pumps with a high thermal mass, but also for domestic appliances. This idea will be further explored in a smart grid, where the price could be changing in seconds and electric equipment is given methods to react on that. Also, personal preferences of customers, for example to use only green energy, can be incorporated in such a power grid.[citation needed]

Technology

The bulk of smart grid technologies are already used in other applications such as manufacturing and telecommunications and are being adapted for use in grid operations. In general, smart grid technology can be grouped into five key areas[29]:

Integrated communications

Some communications are up to date, but are not uniform because they have been developed in an incremental fashion and not fully integrated. In most cases, data is being collected via modem rather than direct network connection. Areas for improvement include: substation automation, demand response, distribution automation, supervisory control and data acquisition (SCADA), energy management systems, wireless mesh networks and other technologies, power-line carrier communications, and fiber-optics. Integrated communications will allow for real-time control, information and data exchange to optimize system reliability, asset utilization, and security.

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Sensing and measurement

Core duties are evaluating congestion and grid stability, monitoring equipment health, energy theft prevention, and control strategies support. Technologies include: advanced microprocessor meters (smart meter) and meter reading equipment, wide-area monitoring systems, dynamic line rating (typically based on online readings by Distributed temperature sensing combined with Real time thermal rating (RTTR) systems), electromagnetic signature measurement/analysis, time-of-use and real-time pricing tools, advanced switches and cables, backscatter radio technology, and Digital protective relays.

Smart meters

Main article: Smart meter

A smart grid replaces analog mechanical meters with digital meters that record usage in real time. Smart meters are similar to Advanced Metering Infrastructure meters and provide a communication path extending from generation plants to electrical outlets (smart socket) and other smart grid-enabled devices. By customer option, such devices can shut down during times of peak demand.[*citation needed*]

Phasor measurement units

Main article: Phasor measurement unit

High speed sensors called PMUs distributed throughout their network can be used to monitor power quality and in some cases respond automatically to them. Phasors are representations of the waveforms of alternating current that ideally in real-time, are identical everywhere on the network and conform to the most desirable shape. In the 1980s, it was realized that the clock pulses from global positioning system (GPS) satellites could be used for very precise time measurements in the grid. With large numbers of PMUs and the ability to compare shapes from alternating current readings everywhere on the grid, research suggests that automated systems will be able to revolutionize the management of power systems by responding to system conditions in a rapid, dynamic fashion[30].

A Wide-Area Measurement Systems (WAMS) is a network of PMUS that can provide real-time monitoring on a regional and national scale. Many in the power systems engineering community believe that the Northeast blackout of 2003 would have been contained to a much smaller area if a wide area phasor measurement network was in place.[31]

Advanced Components

Innovations in superconductivity, fault tolerance, storage, power electronics, and diagnostics components are changing fundamental abilities and characteristics of grids. Technologies within these broad R&D categories include: flexible alternating current transmission system devices, high voltage direct current, first and second generation superconducting wire, high temperature superconducting cable, distributed energy generation and storage devices, composite conductors, and “intelligent” appliances.[citation needed]

Advanced control

Power system automation enables rapid diagnosis of and precise solutions to specific grid disruptions or outages. These technologies rely on and contribute to each of the other four key areas. Three technology categories for advanced control methods are: distributed intelligent agents (control systems), analytical tools (software algorithms and high-speed computers), and operational applications (SCADA, substation automation, demand response, etc). Using artificial intelligence programming techniques, Fujian power grid in China created a wide area protection system that is rapidly able to accurately calculate a control strategy and execute it[32]. The Voltage Stability Monitoring & Control (VSMC) software uses a sensitivity-based successive linear programming method to reliably determine the optimal control solution[33].

Improved interfaces and decision support

Information systems that reduce complexity so that operators and managers have tools to effectively and efficiently operate a grid with an increasing number of variables. Technologies include visualization techniques that reduce large quantities of data into easily understood visual formats, software systems that provide multiple options when systems operator actions are required, and simulators for operational training and “what-if” analysis.

Standards and groups

IEC TC57 has created a family of international standards that can be used as part of the smart grid. These standards include IEC61850 that is an architecture for substation automation, and IEC 61970/61968 — the Common Information Model (CIM). The CIM provides for common semantics to be used for turning data into information.

MultiSpeak has created a specification that supports distribution functionality of the smart grid. MultiSpeak has a robust set of integration definitions that supports nearly all of the software interfaces necessary for a distribution utility or for the distribution portion of a vertically integrated utility. MultiSpeak integration is defined using extensible markup language (XML) and web services.

The IEEE has created a standard to support synchrophasors — C37.118.

A User Group that discusses and supports real world experience of the standards used in smart grids is the UCA International User Group.

There is a Utility Task Group within LonMark International that deals with smart grid related issues.

Smart Grid

There is a growing trend towards the use of TCP/IP technology as a common communication platform for Smart Meter applications, so that utilities can deploy multiple communication systems, while using IP technology as a common management platform.[34][35]

IEEE P2030 is an IEEE project developing a "Draft Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), and End-Use Applications and Loads"[36][37].

NIST has included ITU-T G.hn as one of the "Standards Identified for Implementation" for the Smart Grid that it believed there was strong stakeholder consensus"[38]. G.hn is standard for high-speed communications over power lines, phone lines and coaxial cables.

OASIS EnergyInterop' – is an OASIS technical committee developing XML standards for energy interoperation. It's starting point is the California OpenADR standard.

Government Policy and Financing

Countries

Australia

The Australian Government has committed to investing $100m in smart grids.[2] In early-October it is expected to call for proposals to initiate a study into the technology with the successful location to be announced in early 2010. The study is expected to increase customer awareness and engagement in energy usage and establish distributed demand management and distributed generation management.

Within Australia the adoption of smart grids is hindered by a lack of service level obligations on electricity distribution businesses to connect distributed generation devices in a timely fashion[3].

Canada

The government of Ontario, Canada, through the Energy Conservation Responsibility Act in 2006, has mandated the installation of Smart Meters in all Ontario businesses and households by 2010.

China

As part of its current 5-year plan, China is building a Wide Area Monitoring system (WAMS) and by 2012 plans to have PMU sensors at all generators of 300 megawatts and above, and all substations of 500 kilovolts and above. All generation and transmission is tightly controlled by the state, so standards and compliance processes are rapid. Requirements to use the same PMUs from the same Chinese manufacturer and stabilizers conforming to the same state specified are strictly adhered to. All communications are via broadband using a private network, so data flows to control centers without significant time delays[19].

On May 21, 2009, China has announced an aggressive framework for Smart Grid deployment. Comparing with US and Europe, the Chinese Smart Grid appears to be more transmission-centric. [39]

European Union

Development of smart grid technologies is part of the European Technology Platform (ETP) initiative and is called the SmartGrids Technology platform [4]. The SmartGrids European Technology Platform for Electricity Networks of the Future began its work in 2005. Its aim is to formulate and promote a vision for the development of European electricity networks looking towards 2020 and beyond[40][*citation needed*].

United States

Main article: Smart grid in the United States

Support for smart grids became federal policy with passage of the Energy Independence and Security Act of 2007[41]. The law, Title13, sets out $100 million in funding per fiscal year from 2008–2012, establishes a matching program to states, utilities and consumers to build smart grid capabilities, and creates a Grid Modernization Commission to assess the benefits of demand response and to recommend needed protocol standards[42]. The Energy Independence and Security Act of 2007 directs the National Institute of Standards and Technology to coordinate the development of smart grid standards that FERC would then promulgate through official rulemakings. [43]

Smart grids received further support with the passage of the American Recovery and Reinvestment Act of 2009 that set aside $11 billion for the creation of a smart grid.

Obstacles

In Europe and the US, significant impediments exist to the widespread adoption of smart grid technologies, including:

- regulatory environments that don't reward utilities for operational efficiency, excluding U.S. awards.[*clarification needed*]
- consumer concerns over privacy,[*clarification needed*]
- social concerns over "fair" availability of electricity,[*clarification needed*]
- social concerns over Enron style abuses of information leverage,[*clarification needed*]
- limited ability of utilities to rapidly transform their business and operational environment to take advantage of smart grid technologies.[*clarification needed*]

- concerns over giving the government mechanisms to control the use of all power using activities.[clarification needed]

Before a utility installs an advanced metering system, or any type of smart system, it must make a business case for the investment. Some components, like the Power System Stabilizers (PSS) installed on generators are very expensive, require complex integration in the grid's control system, are needed only during emergencies, but are only effective if other suppliers on the network have them. Without any incentive to install them, power suppliers don't[19]. Most utilities find it difficult to justify installing a communications infrastructure for a single application (e.g. meter reading). Because of this, a utility must typically identify several applications that will use the same communications infrastructure – for example, reading a meter, monitoring power quality, remote connection and disconnection of customers, enabling demand response, etc. Ideally, the communications infrastructure will not only support near-term applications, but unanticipated applications that will arise in the future. Regulatory or legislative actions can also drive utilities to implement pieces of a smart grid puzzle. Each utility has a unique set of business, regulatory, and legislative drivers that guide its investments. This means that each utility will take a different path to creating their smart grid and that different utilities will create smart grids at different adoption rates.

Some features of smart grids draw opposition from industries that currently are, or hope to provide similar services. An example is competition with cable and DSL Internet providers from broadband over powerline internet access. Providers of SCADA control systems for grids have intentionally designed proprietary hardware, protocols and software so that they cannot inter-operate with other systems in order to tie its customers to the vendor[19].

Market outlook

In 2009, the smart grid industry was valued at about $21.4 billion — by 2014, it will exceed at least $42.8 billion. Given the success of the smart grid's in the U.S., the world market is expected to grow at a faster rate, surging from $69.3 billion in 2009 to $171.4 billion by 2014. With the segments set to benefit the most will be smart metering hardware sellers and makers of software used to transmit and organize the massive amount of data collected by meters[44].

Deployments and deployment attempts

In the so called E-Energy projects several German utilities are creating first nucleolus in six independent model regions. A technology competition identified this model regions to carry out research and development activities with the main objective to create an "Internet of Energy"[45]

One of the first attempted deployments of "smart grid" technologies in the United States and was recently rejected by electricity regulators in the Commonwealth of Massachusetts, a US state.[46] According to an article in the Boston Globe, Northeast Utilities' Western Massachusetts Electric Co. subsidiary actually attempted to create a "smart grid" program using public subsidies that would switch low income customers from post-pay to pre-pay billing (using "smart cards") in addition to special hiked "premium" rates for electricity used above a predetermined amount.[46]

This plan was rejected by regulators as it "eroded important protections for low-income customers against shutoffs".[46] According to the Boston Globe, the plan "unfairly targeted low-income customers and circumvented Massachusetts laws meant to help struggling consumers keep the lights on".[46] A spokesman for an environmental group supportive of smart grid plans and Western Massachusetts' Electric's aforementioned "smart grid" plan, in particular, stated "If used properly, smart grid technology has a lot of potential for reducing peak demand that would allow us to shut down some of the oldest, dirtiest power plants... It’s a tool."[46]

General economics developments

As customers can choose their electricity suppliers, depending on their different tariff methods, the focus of transportation costs will be increased. Reduction of maintenance and replacements costs will stimulate more advanced control.

A smart grid precisely limits electrical power down to the residential level, network small-scale distributed energy generation and storage devices, communicate information on operating status and needs, collect information on prices and grid conditions, and move the grid beyond central control to a collaborative network[31].

See also

- Charging station
- Home automation
- Large-scale energy storage
- Pickens plan
- Power line communication
- SuperSmart Grid
- Super grid
- Unified Smart Grid (USA)
- Vehicle-to-grid
- Wide area synchronous grid

Footnotes

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Smart Grid

External links

- The NIST Smart Grid Collaboration Site NIST's public wiki for Smart Grid
- Smart Grid News Free weekly news letter with information on Smart Metering and the Smart Grid
- Opal-RT provides Real-Time Smart Grid Simulator Hardware and Software.
- Video Lecture: Computer System Security: Technical and Social Challenges in Creating a Trustworthy Power Grid, University of Illinois at Urbana-Champaign
- Video Lecture: Smart Grid: Key to a Sustainable Energy Infrastructure, University of Illinois at Urbana-Champaign
- Google Map of AMI & Smart Metering Programmes across the World. Maintained by Smart Metering Project Team at the Energy Retail Association in the UK.
- Similar Google Map showing North American Initiatives categorized by AMR/AMI/Smart Grid Data provided by Enernex, map created by Energy Retail Association project team in the UK.
- How the Smart Grid will recharge Plug-In Electric Hybrids
- Smart Grid Takes Off, Sustainable Industries Magazine.
- Power meters help homeowners track and cut their energy use, The Christian Science Monitor.
- Latest News in Smart Grid and Smart Metering
- Smart Metering and Smart Grids: Intelligent Technology for Utilities
- Who's Who in Smart Grid and Smart Metering
- Smart Policy: Achieving a Smart Grid
- Smart Grid Software: I.S/g