Comparison of Smart Grid Technologies and Progress in the USA and Europe

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Abstract This work discusses historical and technical events in USA and Europe over the last few years that are aimed at modernizing the electric power grid. The US federal government has ratified the "Smart Grid Initiative" as the official policy for modernizing the electricity grid including unprecedented provisions for timely information and control options to consumers and deployment of "smart" technologies. European countries are unified in researching and developing related technologies through various structures supported by the European Union. This chapter presents the development of smart grids and an analysis of the methodologies, milestones and expected evolutions of grid technologies that will transform society in the near future.

Keywords Control · Distributed generation · Power electronics · Power systems · Smart grid · Smart metering · Storage · Calibration · Intelligent sensors · Nuclear measurements · Production facilities · Protocols · Sensor phenomena and characterization · Sensor systems · Temperature measurement · Temperature sensors · Wireless sensor networks

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1 Introduction

The present-day electric grid was built about a century ago in most industrialized countries and has been growing in size and capacity ever since. Transmission lines connect large centralized power sources to the grid and have been technologically updated with automation and human monitoring over the last few decades. The electrification of our society has empowered countless advances in other fields such that the US National Academy of Engineering ranked it as the greatest engineering achievement of the last century [41]. However, this transformation was mostly in the transmission realm and not in the distribution milieu since the latter has traditionally been considered as user endpoints of service, where power was delivered to traditional loads. The last two decades saw a steady growth of distributed generation, with plans for higher penetration of renewable energy sources, and the policies on electricity distribution have been supporting needs for a "smart grid" for many reasons that will be discussed in this chapter. Centralized power plants have enormous economic constraints and benefits, and utilities have been trying to use their assets more efficiently. As an example, typically, 20 % of the US generation capacity is used only for 5 % of a year to meet peak demand and is based on coal and gas power plants, which cause environmental concerns and greenhouse gases (GHG) emissions. A paradigm shift in distribution engineering is viewed as the next frontier of advancement in electric power systems, and the smart grid is expected to introduce unprecedented changes in the distribution systems worldwide. Both the US and European economies have taken the lead in establishing some early concepts and policies for realizing the smart grid. In this chapter, a comparison of the various smart grid technologies and the path of progress in the USA and in Europe are presented.

2 Evolution of the Smart Grid in the USA and Europe

Conceptualization of techniques to improve the intelligent interaction of distributed assets for smart grids emerged in the 1980s as a call to modernize the grid, allowing deeper penetration of alternative and renewable energy sources. The first references to the term *smart grid* were provided around 2004 by Amin [5], Amin and Wollenberg [7]. While some common characteristics of a smart grid exist, Europe and USA have been following different paths to make their respective grids smarter.

2.1 Trajectory in the USA

The electric grid in the USA is composed of approximately 15,000 generators operating in 10,000 power plants, accounting for approximately 3.95 million MWh (as of 2009), with approximately 160,000 miles of high-voltage transmission lines (at voltages typically above 280 kV) [4, 13]. The electric grid in the USA evolved from small-rated centralized power stations, such as the historical Pearl Street Station in Manhattan, NY (such power stations supplied DC electricity to relatively smaller-rated loads in the late nineteenth century) to the interconnected AC system of present day that crisscrosses North America [26]. The present-day massive North American grid consists of three large asynchronous interconnections—the western electricity coordinating council (WECC) system, the eastern interconnection, and Texas (ERCOT)—and has been referred to as the "most complex man-made machine" [35]. The evolution of the smart grid in the USA may be traced to several innovations in the transmission grid, such as the wide-area measurement, fast controls, the installation of power system stabilizers, phase shifting transformers, flexible AC transmission system devices (FACTS), and phasor measurement units (PMUs). Additionally, the advent of advanced control room visualization has heralded the template for the smart grid. Public awareness and concomitant push for more renewable energy sources in the grid have also provided some impetus to the integration of newer technologies in the grid.

However, the modernization of the electricity grid has been largely restricted to the transmission systems and did not penetrate the distribution system level as much. This may be attributed to factors such as higher variability in system scenarios at the latter level and a relatively low economy of scale when compared to the transmission systems. Several legislative mandates have provided various opportunities for the modernization of the electric grid in the USA. Figure 1 provides a timeline of some events related to the electricity grid in the USA that have served as harbingers to important changes via mandates and legislations.

2.2 Trajectory in Europe

The unification of the European grid was achieved in parallel to the economical unification of European countries. This process has been slow, due to the high cost of building new infrastructures and to historical events such as the two World Wars and the political separation of Eastern and Western Europe for more than four decades.

The idea of a pan-European grid was first discussed by the League of Nations in the 1920s. This became a reality only in 1951 with creation of the Union for the co-ordination of production and transmission of electricity (UCPTE, which eventually became UCTE), which was aimed at interconnecting the grids of France, Germany, and Switzerland. Similar associations were created in other regions of Europe, such as NORDEL or SUDEL. But during the Cold War, a real interconnection of the Western and Eastern parts of Europe was nearly impossible, and European countries reorganized such interests only after 1990, with the fall of the Iron Curtain. In 2008, the regional associations ETSO, ATSOI/UKTSOA (Ireland, Great Britain), NORDEL (Finland, Sweden, Norway, and Eastern

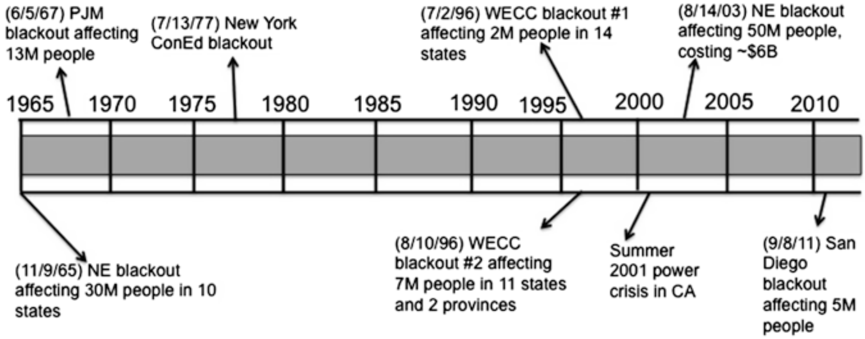


Fig. 1 Timeline of major events in the US electric grid

Denmark), UCTE (23 continental European countries), and BALTSO (Baltic countries) merged into the European Network of Transmission System Operators for Electricity (ENTSO-E), which now coordinates 41 transmission system operators (TSOs) from 34 countries [14]. Smart grid policies in Europe are relatively new, while at the same time the European grid is becoming more interconnected and sees investments decrease. However, the sense of ownership and contribution of each individual country to the whole grid is different from how the USA directs initiatives through its Department of Energy (DOE). Some recent EU initiatives are as follows:

- The European energy program for recovery (2009), which has some similarities to the US Stimulus fund. This program was aimed at speeding up and securing investments for projects in the energy sector.
- An overall energy efficiency action plan (2007–2012) establishes a firm objective of 20 % improvement.
- The European energy infrastructure package identifies smart grids as the key infrastructure for energy modernization in Europe.
- A Competitiveness and Innovation Framework Program (CIP) proposes an Intelligent Energy for Europe program.
- The European Energy Research Alliance (ERRA) aims at accelerating the development of new energy technologies by maximizing funding sources, facilities, and complementarities among institutes in participating countries.

3 Governing Bodies in Smart Grid Development

The US Smart Grid Initiative is the official policy of grid modernization in the USA as formalized by the 2007 Energy Independence and Security Act (EISA07) [3]. Under the purview of this legislative mandate, the US smart grid is characterized by:

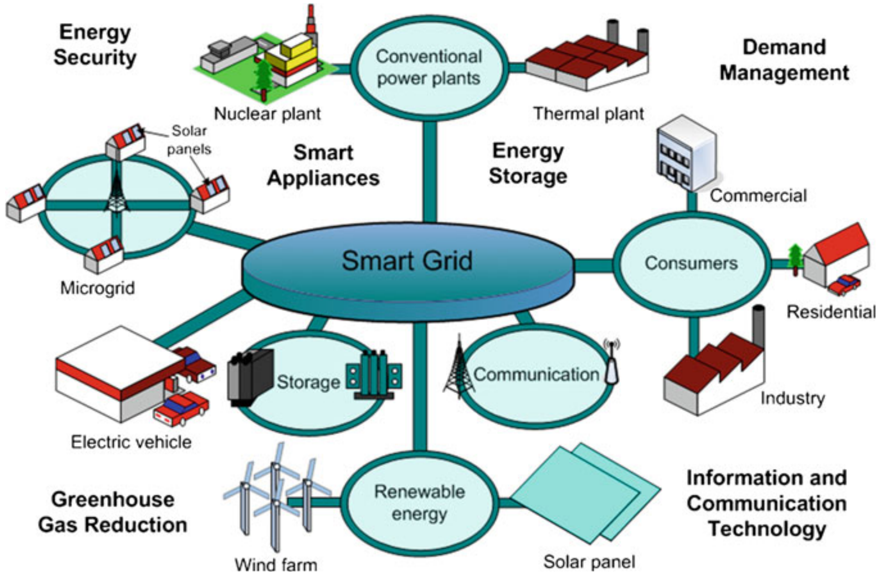


Fig. 2 The future electric smart grid

- Increased digital information and controls.
- Dynamic optimization of grid operations, including cyber security.
- Deployment of distributed resources including renewables.
- Incorporation of demand-side resources and demand response.
- Deployment of "smart" technologies and integration of "smart" appliances and consumer devices.
- Deployment of storage and peak-shaving technology including PHEV.
- Provision of timely information and control options to consumers.
- Standard development for communication and interoperability of equipment.
- Identification and lowering of unreasonable barriers to adopt smart grid technology, practices, and services [3].

An illustration of an implementation of the smart grid is depicted in Fig. 2 The National Institute of Standards and Technology (NIST) provides a conceptual model that defines seven important domains: bulk generation, transmission, distribution, customers, service providers, operations, and markets [34].

In the EU, the smart grid strategy is motivated by concepts of innovation with regard to social and environmental reforms for an interactive economy. The European energy policy relies on [21]: (1) security of supply, (2) sustainability, and (3) market efficiency. In addition, six goals have been set for the EU energy strategy to: (1) achieve the highest levels of safety and security, (2) achieve an energy-efficient Europe by improving buildings, transportations, and distribution grids, (3) extend Europe's leadership in energy technology and innovation, (4) empower consumers, (5) build a European integrated energy market, and (6) strengthen the external dimension of the EU energy market. The European Strategic Energy Technology Plan includes eight European Industrial Initiatives (EII) in the field of energy. The EII on electrical grids is called the European Electricity Grid Initiative (EEGI) and has a budget estimated to €2 billion over a period of 10 years with guidelines and activities for R&D and a program with 20 large-scale demonstration projects [22].

The EU established the Third Energy Package in 2007 with objectives and regulations for the implementation of smart grids stating that all European citizens have a range of energy-related rights, such as consumer choice and fair prices. Dispositions are also taken to favor international energy (electricity and gas) trade, collaboration and investment, separation of generation and supply from transmission networks, decentralized generation and energy efficiency, smart meters and effective national regulators. The European Technology Platforms (ETP) began to operate in 2005 [17] in formulating and promoting a vision for the development of smart grids for year 2020 in compliance with EU policy. A "Smart Grids Task Force" was created in 2009 and is composed of European Commission officials, experts from the industry, policy makers, and academia [19]. The first projects related to smart grids were grouped within the IRED (Integration of Renewable Energy Sources and Distributed Generation into the European Electricity Grid) cluster. Over 60 projects in the fields of smart grids have been supported by the 6th Framework Program (FP6) and correspond to an investment of about €190 million. FP7, the current program, will run until 2013 and has a total budget of €51 billion, with 7 % of it dedicated to energy-related projects [16]. Currently the related EU associations for promoting smart grid projects are as follows:

- The European Regulators Group for Electricity and Gas (ERGEG) and the Council of European Energy Regulators (CEER), which allow national regulators to cooperate.
- The new agency for the Cooperation of Energy Regulators (ACER), a complement to the two previous organizations and ENTSO-E.
- The European Distribution System Operators Association for Smart Grids (EDSO-SG).
- The Union of the Electricity Industry (EURELECTRIC), which represents the common interests of the electricity industry at the European level.

4 Enabling Technologies

Several technologies have to mature in order to make the smart grid a reality [40, 42]:

4.1 Distributed Generation

Distributed generation (DG) (also referred to as embedded generation or dispersed generation) refers to small rating electricity sources that are typically decentralized and located close to end-user locations on the distribution side of the electric grid. These may include conventional as well as renewable energy sources. The interconnection of DG to the grid provides a variety of advantages including on-demand power quality of supply, enhanced reliability, deferrals in transmission investment, and avenues for meeting renewable mandates in the face of growing disinvestments in transmission assets—all of which cater to the smart grid philosophy. However, the interconnection of DG is a challenge due to the safety, control, and protection issues associated with bidirectional flows of electricity. In the USA, the Energy Policy Act of 2005, enacted by the 109th Congress, recognized the IEEE 1547 Standard as the national technical standard for interconnection of DG to the electric grid [2]. Further information about DG is available in [24].

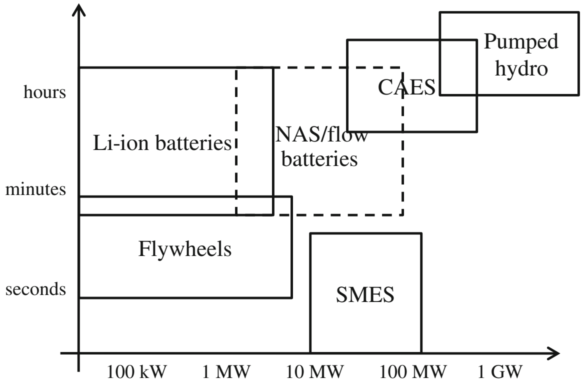
4.2 Energy Storage

Electricity is a highly perishable commodity that must be consumed within a very short span of production and cannot be easily stored, especially in high quantities. Alternatively, it may be converted into other forms such as mechanical or electrochemical energy. Storage technologies enable these processes and are among the desired features for the smart grid. Multiple existing technologies are compared in Fig. 3. Storage, which can be distributed in the grid, (i) makes the grid more efficient [36]; (ii) enables load leveling and peak shaving, while it reduces dependency on spinning reserve; (iii) improves grid reliability and power quality; (iv) provides ancillary services, supplying reactive power for voltage regulation; and (v) supports T&D investment deferring. Energy storage with power electronics interfaced units can create virtual rotational inertia, the so-called virtual synchronous generators (VSG), which can reduce the rate of change of frequency and frequency deviations [12].

4.3 Power Electronics

Power electronics is fundamental in the development of smart grids because a deeper penetration of renewable and alternative energy sources requires sophisticated power converter systems. Typically, a power converter is an interface between the smart grid and local power sources [9]. Solar PV and wind play a significant role as alternative sources for integration in smart grids and are

Fig. 3 Comparison of discharge duration versus rated power for some grid energy storage technologies



increasingly being installed in residential and commercial locations (typically with a power range of a few kW) as well at high rating in the high-voltage transmission grid. The intermittent nature of these sources affects the output characteristics of generator and converter sets. A power electronics converter is deemed necessary to smooth the output to desired characteristics and to allow energy storage during surplus of input power and compensation in case of lack of input power. The following characteristics are important for power electronics systems for smart grids:

- High efficiency: Only a negligible part of the power should be dissipated during conversion stages;
- Optimal energy transfer: All renewable energy sources are energy constrained and, as such, need algorithms to achieve the maximum power point which must be considered in the design of the power electronics interface;
- Bidirectional power flow: Power converters have to be able to supply the local load and/or the grid;
- High reliability: Continuity of service is a major issue when delivering energy;
- Synchronization capabilities: All power sources connected to the grid have to be fully synchronized, thus ensuring high efficiency and eliminating failures; therefore, standards such as IEEE 1547 should be incorporated in power electronics interfaces [28];
- Electromagnetic interference (EMI) filtering: The quality of the energy injected into the grid must adhere to apt electromagnetic compatibility (EMC) standards;
- Smart metering: The interface between the local source/load and the grid must be capable of tracking the power consumed by the load or injected into the grid;
- Real-time information must be passed to an automatic billing system capable of taking into account parameters such as energy bought/sold in real time, informing end users of all required pricing parameters;

- Communications: The intelligent functioning of the smart grid depends on the capability to support communications layer in tandem with an energy delivery layer in the grid; and
- Fault tolerance/Self-healing: A key issue is a built-in ability to minimize the propagation of failures and resilience against such local failures. This capability should be incorporated with monitoring, communication, and reconfiguration features of power electronics systems. Additionally, power electronic interfaces must be configured to avoid nuisance trips.

4.4 Control, Automation, and Monitoring

A smart grid is a highly complex, nonlinear dynamic network of distributed energy assets with bidirectional flow of power and information that presents many theoretical and practical challenges. Monitoring and control are key issues that need to be addressed to make it more intelligent and equip it with self-healing, self-organizing, and self-configuring capabilities. This requires much more sophisticated control, sensing, and computer-oriented monitoring than in the contemporary grid, where grid operations are rather reactive, with a number of critical tasks performed by human operators. Therefore, some modern control techniques have been claimed to be the best fit for smart grids, for example, agent-oriented programming, implementing computational intelligence into distributed systems operation [15]; however, most of these are yet to transcend the research domain into large-scale deployment. A combination of agent-based control techniques and power electronics possess the potential to create an intelligent and flexible interface between consumers, storage, DGs, and the network, as well as among network areas. Figure 4 illustrates different power electronics layers to integrate a cluster of prosumers (an entity in the future grid capable of both producing and consuming electric power) into the grid.

The two-way communication ability of smart meters allows the transmission of delivered and generated energy data along with actionable commands to customers. With technologies such as WIFI, ZigBee, and home area network (HAN) communication systems, smart meters can now act as interfaces for energy management entities, customers, and utilities to control a number of appliances within a residential home based on price signals [32].

Power quality analyzing capabilities of smart meters may improve the ability to identify system and customer voltage deficiencies, harmonic distortions, and onset of equipment failure. Daily energy usage and generation profiles may be recorded for forecasting-relevant system parameters. Threshold voltage events can trigger communication with utilities for providing alerts to disturbances, prior to customer equipment failure or discomfort. These functionalities may also improve the ability of utilities to locate the source of system events, which is a difficult and complex task on the existing electric distribution system, but at may introduce the

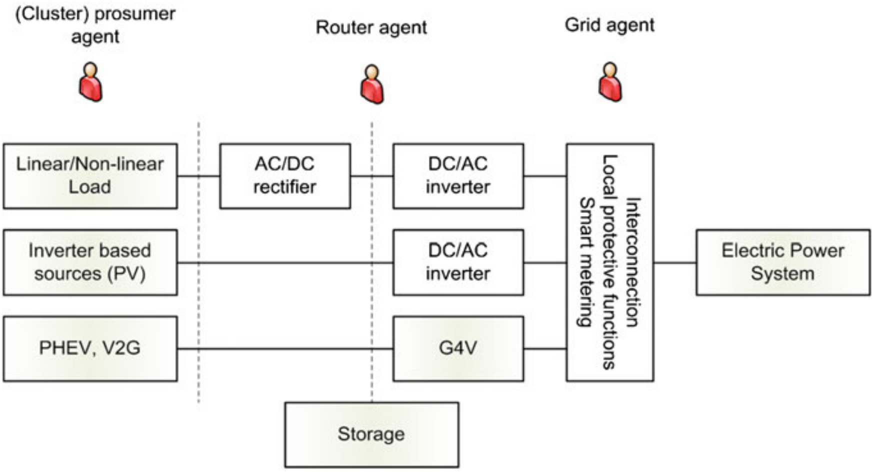


Fig. 4 Intelligence-based control structure for power electronics in smart grids

risk of increased susceptibility to cyber intrusions by malicious agents [11]. Several utilities in the USA and Europe have already seen improved power quality due to the installation of smart meters [31].

4.5 Demand-Side Management

Demand-side management (DSM) refers to the ability to change energy consumption patterns and characteristics via structured programs. Historically, most DSM programs aimed at achieving targets in energy efficiency, while some conservation programs aimed at deferring investments in new assets (including generating facilities, power purchases, and transmission and distribution capacity additions). However, with the advent of the smart grid, DSM may provide paradigm shifts in the normal operation of the electricity market or from government-mandated energy efficiency standards. In the last few years, there has been an increased interest in dynamic pricing, i.e., a time-varying pricing at the end-user level, different from the state of the art of tariffs. Dynamic pricing, which is available in the US bulk power (transmission) markets since mid-90s following deregulation of the industry, has enabled economic efficiency, fostered investments in technological innovations, and for the most part removed the ills of market power and monopoly [30]. Such a differentiated or tiered rate of electricity in the distribution system is viewed as an enabler for the smart grid. When enabled with such information on dynamic pricing of electricity, customers and utilities will need to interact via DSM structures aimed at increased energy efficiency, lowered cost of engaging inefficient and costly generators at peak periods, coordinated charging of plug-in hybrid electric vehicles (PHEVs), or other similar objectives. Several dynamic pricing models have been proposed in order to better reflect the actual cost of producing energy on the specific day and time and provide incentives to customers to become more active in controlling their electricity consumption [33, 37]. The following time-varying pricing methodologies are viewed as possible enablers of DSM:

- Time-of-use (TOU) electricity rates have been shown to be effective in promoting customer participation in demand management [37]. TOU rates use predetermined time intervals during which electricity use is recorded. Each time interval has a fixed price that is proportional to the electricity availability during that same time interval.
- Real-time pricing is a methodology whereby the customer is informed a time period ahead of the electricity price so as to make rational decisions regarding the consumption of electric energy. The retail price of electricity in this pricing methodology floats based on the actual cost of electricity. If the time period is 1 h, then real-time pricing is known as hour-ahead pricing.
- Critical peak pricing is used to "force" customers to avoid consuming electric energy during specific peak periods. These periods are well defined by the utility, and the cost of electricity during these periods is increased significantly.
- The peak time rebate has a similar concept as the critical peak pricing. Instead of a penalty, the conscious customer receives a reward for reducing their electricity consumption below a certain baseline. If the customer consumes more than the baseline, there is no penalty imposed.

Data management is critical for the widespread operation of the smart grid in the near future, because vast raw data will have to be processed, aggregated, validated, and transmitted for further processing and analysis.

4.6 Distribution Automation and Protection

Smart grid technology supports a wide range of applications in power systems, such as protection and automation of the distribution system and security. It is possible to design self-healing protection systems using the capabilities of the advanced distribution automation (ADA) [25]. The protection of the power system is a critical necessity in order to achieve continuity, reliability, and security of supply. Protection deals with the detection and clearance of abnormal system conditions such as faults and overloads. High penetrations of DG can compromise existing protection schemes, which are based on single sources supplying unidirectional power through radial distributed lines. In the smart grid, where bidirectional flow of electricity through partially networked systems in the distribution milieu will be prevalent, protection mechanisms are adaptive and incorporate intelligent automated functions. Recent activities in protection engineering focus on developing microprocessor-based devices called intelligent electronic devices

(IEDs). Such devices may be smart distribution switches or integrated solutions for substations. Standard IEC 61850 (Communication Networks and Systems in Substations) provides authoritative information relevant to the design of substation automation [29].

4.7 Communication Systems

Self-healing systems have been sought to be incorporated into power systems, especially as the complexity and interactions of several market players significantly increase the risk for large-scale failures. Reconfiguring the system in islanded mode may require a hitherto unknown rate and amount of data exchange, two-way communication links, and advanced central computing facilities. Decentralized intelligent control could enable islands to accommodate their native load and generation in a more reliable and efficient manner. Local controllers may ensure that each island is operating within the security limits, safeguarding the electricity supply to its customers [6]. A self-healing system should be based on a wide-area monitoring network that incorporates a variety of sensors, such as PMUs that obtain phasor measurements by synchronizing with each other through the global positioning service (GPS) [6, 10].

Measurements and signals obtained from sensors may be used either by local (distributed) or centralized controllers to enable the self-healing of the system under disturbance or fault conditions. These measurements and signals may be submitted for processing to a single controller, despite the fact that they may be originating from different proprietary networks [8]. IEEE Standard 1451.4 requires analog sensors to have a transducer electronic data sheet (TEDS) to provide calibration information to the data acquisition system [27, 43]. Figure 5 shows how several communication technologies can be applied for such data, according to their characteristics. Ranges of operation and bandwidth of these technologies vary significantly, and some of them may be chosen for HAN, while others may be used for longer distances as from houses to concentrators or between substations [31].

Two-way communication enabled smart appliances, smart meters for control of sources, and loads, and storage must be implemented in a platform that allows both digital information and electric energy to flow through a two-way smart infrastructure. The requirements for these communication infrastructures are reliability and resilience, bandwidth, interoperability and costs. Several communication protocols and media are currently under various stages of research and development R&D for implementation in smart grids. Examples include: broadband over power line (BPL) and power line communications (PLC), which use existing power lines to transmit information; Ethernet, DSL, and optic fiber, already in use for the Internet; ZigBee, and WIFI, which are already used for HAN applications; WiMaX, a “super-WIFI”, with a much higher range; and 3G, LTE/4G, and other mobile telephone communication protocols.

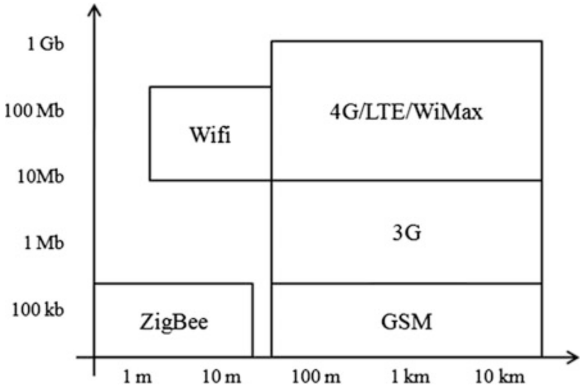


Fig. 5 Characteristics of some wireless communication technologies: bandwidth versus transmission range

5 Comparative Metrics for USA Versus Europe

Making the grid smarter requires considering all aspects of smart grids as part of the decision-making process. This section compares the practices in the USA and the EU on several topics for the development of smart grid technologies.

5.1 Legislation in the USA

The legislation that led to the present-day US Smart Grid Initiative might be traced back to the 70s, when deregulation was initially introduced as a direct result of the Arabic oil embargo that escalated a nationwide energy crisis. In 1977, the Federal Power Commission (FPC) was restructured to form the Federal Energy Regulatory Commission (FERC), with the objective of regulating energy transactions and transmission across different states in the Union. The National Energy Act of 1978 was passed to conserve energy and increases efficiency by judicious use of resources and amenities by utilities and introduced the Public Utilities Regulatory Policies Act (PURPA), which advocated the need for small power productions, for cogeneration and for renewable energy sources that could compete as independent power producers (IPPs) in the electricity market with other utilities. The 102nd Congress of the USA passed the Energy Policy Act of 1992, which included provisions for alternative fuels, electric motor vehicles, energy efficiency improvement, and energy conservation techniques [1]. FERC mandated open transmission access, with the mandated open-access transmission tariff (OATT) requiring that all investor owned utilities (IOU) make separate functionalities of generation, distribution, transmission, and marketing services. It also mandated the creation of independent system operators (ISO), eventually making possible the creation of an open-access same-time information system (OASIS)—a web-based secure database of transmission system-related information. These orders were the

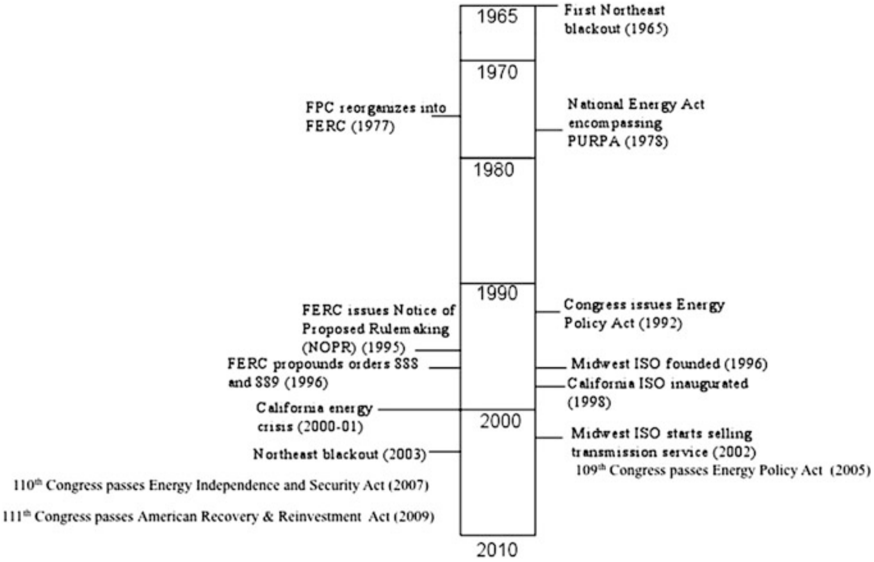


Fig. 6 Key US legislative events vis-à-vis the smart grid

template for the evolution of the deregulated electricity market structure that is currently in place in the USA.

Following the Northeast blackout of August 2003 in the USA, the 109th US Congress passed the 2005 Energy Policy Act, with provisions for tax incentives and subsidies for renewable energy integration and energy efficiency technologies. Figure 6 depicts a timeline of some key legislative events in US history vis-à-vis the smart grid. The 110th US Congress is credited with passing the EISA07, which explicitly characterized the smart grid through the Smart Grid Initiative in Title XIII. The other highlights of this act included electrifying the transportation fleet, reductions in fossil fuel usage in certain sectors, and carbon sequestration. This was followed by the American Recovery and Reinvestment Act of 2009 (ARRA09), passed by the 111th US Congress, which included provisions for energy infrastructure improvements via the implementation of the smart grid. Table 1 lists some details of selected smart grid projects in USA supported under ARRA09 [38]. The Smart Grid Clearing House is a web resource that lists all ARRA09-funded smart grid projects geographically as well as according to their technical focus.

5.2 Legislation in Europe

Energy needs are responsible for 80 % of all European GHG emissions [17]. Therefore, climate change legislation and energy policy have been intimately

Table 1 Selected US smart grid projects from Smart Grid Clearing House [38]

Project type	Number of projects
Automated meter infrastructure (AMI)	81
Customer systems	8
Distribution systems	15
Equipment manufacturing	2
Integrated systems	54
Regional demonstration	16
Storage demonstration	16
Transmission system	10
Total number as of June 2011	~202

linked with a strong impact on investment decisions from private companies. As a consequence of the Kyoto protocol, European leaders made a unilateral commitment to reach three legally binding objectives by 2020, known as the "20–20–20" targets [18]:

- Reach a 20 % share of energy consumption coming from renewable sources.
- Achieve a reduction of 20 % of primary energy use through energy efficiency measures.
- To reduce GHG emissions by at least 20 % below 1990 levels.

With the Third Energy Package, additional requirements were introduced, such as the encouragement to roll out 80 % smart meters in Europe by 2020 [23]. GHG target reductions may be increased to 30 % if other major emitting countries set themselves ambitious objectives. A proposal to cut emissions by 80–95 % by 2050 has also been suggested. Table 2 shows a list of selected smart grid projects in Europe supported by EU funding in the last few years [20].

5.3 Barriers

Several barriers may slow down the development of smart grids on both continents, as depicted next. A first issue is related to financing. During 2009, stimulus plans were used for funding dozens of projects. However, as more and more governments are taking austerity measures, this funding is expected to decrease, or not be renewed, and will need to be either replaced or supplemented by private funding sources. This raises the question of the real interests of the many stakeholders in the smart grid. The cost to modernize distribution networks is high, and utilities may consider if the benefits will overweigh the costs. Moreover, the smart grid requires utilities to make significant changes to their present business models (e.g., reducing demand is contradictory with present-day models). Regulators are expected to balance costs in order to ensure that each player finds an acceptable ratio between the costs and returns on investments. They should also enable dynamic electricity pricing, a requirement for demand response actions, and DSM

Table 2 Selected EU smart grid projects from European Commission CORDIS [20]

Project	Focus
More-microgrids (FP6)	DER, microgrids
FENIX (FP6)	RES integration
EU-DEEP (FP6)	Business models
ADDRESS (FP7)	DER integration, demand management
SmartHouse/SmartGrid (FP7)	Smart buildings
MERGE, G4V (FP7)	Impact of electric vehicles
Green eMotion (FP7)	Business models for electric vehicles

programs to achieve success. The acceptance of consumers regarding smart metering and changes in general is a challenge. In some US states, consumers raised concerns to the installation of smart meters, regarding an increase in the electricity bill, or the privacy of information transmitted to the utility. Technology maturity and availability presents another challenge, especially regarding DER integration and control. The operating security is also critical, as shown by the Stuxnet case [39]. The establishment of standards for smart grids is also a crucial step. By allowing components to interact with each other, and ultimately to reduce costs, standards will enable true interoperability between assets produced by various companies. The US NIST, IEEE, IEC, and other organizations have been working on several standardization activities.

6 Path Forward

The EU and the USA have different approaches in fostering smart grid technology. Europe has been influenced by concerns derived from the diversity and evolution of power grids across European countries, while the USA needs to increase security and to respond to the predicted growth in demand for a long-term vision. It is expected that such technologies will have widespread growth subject to economies of scale. Distribution networks will dramatically change in the near future, and energy storage is expected to become increasingly available, even at the distribution level, in order to compensate the intermittent nature of renewable energy sources that will penetrate the distribution sector. Communication and user interfaces will be pervasive, and the integration with the new web of things (WoT) will allow individual home and business electric devices to be controlled and operated from remote locations. Power distribution will be more controllable and dispatchable, and new distribution systems will have massive automation and sensing systems that will allow any user to interact with any other one on the electrical network. A smart grid is expected to emerge in the USA and in Europe in the next decade and to evolve thereafter; notwithstanding the avatar of this smart grid, which will be a function of the policies shaping this evolution, the desired characteristics of resilience, sustainability, increased energy efficiency, engaging highly dispersed assets with temporal and spatial stochastics, and breeding a new class of informed customers who engage in the grid operations are expected to be achieved.

Dedication We dedicate this chapter to the memory of our friend and co-author, Dr. Benjamin Blunier, formerly an Associate Professor at the University of Technology of Belfort-Montbéliard (UTBM), who passed away on february 23, 2012.

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