

Future Intelligent Power Grids: Analysis of the Vision in the European Union and the United States

ABSTRACT

The future of power grids is expected to involve an increasing level of intelligence and integration of new information and communication technologies in every aspect of the electricity system, from demand-side devices to wide-scale distributed generation to a variety of energy markets. This paper provides a general outlook of the definition of this future in the US and the European Union and compares two approaches-GridWise™ and SmartGrid. It describes the contexts in both the worlds, as they influence the two visions of the future intelligent power grid, and as they form foundations at each respective federal level for supporting research in this field. The similarities and complementarities of the two research programs are examined. Within the framework of a solid precedence for trans-Atlantic co-operation in energy research, the time would seem optimal to set in motion active collaboration and educational exchange on GridWise and SmartGrid research.

This paper will help energy policy makers to better understand the key issues determining the two different approaches and the two different policies derived from them; as well as a comparison of the solution provided in each case. This work will also be useful for researchers and industry decision makers to be aware of trans-Atlantic approaches, opportunities, and resources looking toward future, more intelligent and interconnected power grids. © 2006 Elsevier Ltd. All rights reserved.

Keywords: Energy Policy Analysis; Intelligent Power Grid Visions; Analysis of Opportunities

1. Introduction

During 2004, a group of European scientists and industry leaders directed by the European Commission (EC) visited key research centers in the United States in the field of distributed energy and demand response techniques to share knowledge in this field. As a result of this exchange of ideas, a conference in Brussels was organized, where both teams presented their related programs and recent work.¹ The event, led by the EC, united representatives mainly from Europe and the US, including the Department of Energy (DOE), as well as the Californian Energy Commission (CEC), the National Renewable Energy Laboratory (NREL) and the Electric Power Research

Institute (EPRI). Others included Japan, Canada and Australia.

This first official exchange of information in this field showed that some key ideas were being developed in parallel by both worlds (US and Europe). And, these key ideas were leading to development of coincident visions of future intelligent power grids, responding to the necessity of modernizing the architecture of the electric system. Two of these visions are the DOE's, GridWise™, and the EC's SmartGrid.

GridWise and SmartGrid are focusing efforts from industry, researchers and their respective governments to harmonize the different interests in common visions, separately in the US and Europe.

This paper provides a simplified background picture of the current situation in the two worlds as pertains to intelligent power grids, analyzing the key aspects driving the two visions. It also presents these two visions with their similarities and differences. The last point suggests opportunities for collaborating between the two worlds,

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¹ The following, Second International Conference on Integration of Renewable and Distributed Energy Resources will be held in Napa Valley, CA, December 4–8, 2006. Website: www.2ndintegration-conference.com.

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doi:10.1016/j.enpol.2006.09.001

as an advantage for increasing the competitiveness in both environments.

This work is interesting for energy policy makers on both sides of the Atlantic, providing them with a panorama of key issues and a general understanding of the areas of research surrounding intelligent power grids; for decision-makers and researchers introducing them to parallel scenarios for the development of the future intelligent power grid concept; and for industry leaders to know the vision of the future grid being promoted by team leaders in both worlds.

2. Analysis of the Situation

The power infrastructures in both Europe and the US are being quickly outdated even with very different policies and socio-economical contexts. Key parts of the solution for both of them seems to be the evolution toward a more intelligent power grid, which will require increased research and development in a series of key areas. Identifying these key areas starts with an analysis of the context in the EU as well as in the US; examining energy supply, the politico-economic basis, energy policy, and power infrastructure. Then from a comparison between the two situations, the directions research is taking in each environment will be better understood.

The contexts in the two worlds are outlined below as relates to the development of the future intelligent power grid concept; this overview should not be considered as a complete description of each situation beyond what pertains to future intelligent power grids.

2.1 European Union (EU)

2.1.1 Resources

To ensure energy supply is a main concern in Europe. In the EU 15 (EU before the last expansion), the base of the electricity generation was coal (30%) and nuclear (33%); with a smaller share of natural gas (14%), renewable energy sources (RES) (13.8%), oil (5%), and other fuels (Eurostat, 2005). With the inclusion in EU of new member countries (relying mainly on nuclear and coal), the share of these two fuels has grown and in the future, an increase in the gas sector has been forecast (COM, 2003a, b).

The long-term security of oil supply for the EU depends largely on external supply (Stevens, 2005) because indigenous oil reserves are economically less attractive and quite limited. Unlike oil, the supply of natural gas to the EU is essentially a regional issue, because the EU is structurally dependent on indigenous production in Norway, the Netherlands and the UK and on large volumes of imported gas from Russia and Algeria (CIEP, 2004; EU, 2005a). The RES in Europe present significant potential; in 2004, contributing around 14% to the Union's overall gross electrical generation, of which 71% is hydro, 14% biomass, 13% wind and the rest solar and geothermal (EC, 2005), with a challenge to increase their

contribution to 21% by 2010 (COM, 2002, 2006).

2.1.2 Politico-Economic Context

Compared to the US, the EU is relatively recently established (10 out of the 25 countries just recently joined, and two more countries should normally join the Union in 2007) and is in the process of contending with this growth and harmonization of member state laws. The politico-economic context in the EU is defined by the intergovernmental and supranational union of 25 European countries, known as member states, every one of these countries with its own socio-cultural baggage, as well as differing economic pictures. The legislative process involves the EC, European Parliament and Council of the EU. The Council is the legislative body. The Parliament supervises the EC budget and can amend or veto in many policy areas. The EC is an autonomous decision-making institution with law-proposal-making attributions in some specific domains, such as the liberalization of the energy market, in which the proposed new laws should be enacted by the Parliament and Council (EU, institutions).

The EC's commitment to the Kyoto protocol and the high public awareness of energy consumption in Europe impact policy decisions, such as through policies targeting increased use of RES and high efficiency technologies in the power grid.

One of the main objectives of the EU's progressive enlargement is economy stabilization within the new member countries. This stabilization process will entail an increase in their energy consumption, as well as an increased need for investment in current power infrastructures.

2.1.3 Energy Policy

The context for European energy policies has changed over the last 30 years as a result of political, environmental, economic and energy market developments. At its origin the European energy policy was based on heterogeneous national policies. The EC's Directives are aimed to homogenize these policies. The first electricity and gas Directives (96/92/EC; 98/30/EC) abolished the principle of a monopoly provider and allowed large users to choose their electricity and gas supply. Many member states responded to these initiatives by moving to establish competitive markets. With the more recent gas and energy Directives (2003/54/EC; 2003/55/EC and Regulation 1228/2003) competition in energy markets was extended to non-households for all member states in 2003. In 2004, the EU grew with 10 new countries. This enlargement included countries with very different energy policies; most of them derived from specific patterns of energy supply and demand, based on their former orientation towards the Soviet Union (Correljé and van der Linde, 2006). Foreseeing this situation, the EC set up the European Regulators Group for Electricity and

Gas (EREG) in 2003 (2003/796/EC). This regulatory group acts as an advisory group of independent national regulatory authorities to assist the EC in consolidating the internal markets for electricity and gas. In particular, it should help ensure a consistent application in all member states of the recently adopted new electricity and gas Directives, as well as the new regulation on cross-border exchanges of electricity.

2.1.4 Power Infrastructure

A main characteristic of the power infrastructure in Europe is that its evolution stems directly from the different energy policies regulating each country, which creates very different patterns for the different EU members. The target of building up an efficient European energy market requires an improvement in several weak points in the power infrastructure (COM, 2003). The weak interconnections between the countries is the first of these weaknesses, which is responsible for dividing the European area into at least four distinct electricity markets: the United Kingdom and Ireland; NordPool of the Scandinavian countries; the Iberian Market; and Central EU (IEA, 2002; COM, 2005a). One concern faced is the risk of the European transmission systems becoming even more complex, and potentially unstable, as the network widens. And, so far, utility industry privatizations have largely failed to create an environment suitable for investment in power plants and transmission lines. The second weakness is the lack of introduction of technologies that allow demand response. Encouraging consumers to respond to market prices would be necessary for building an efficient energy market, but these technologies are still under development. Finally, the third weakness is in the context of EU environmental targets, the reinforcement of transport and distribution capacity to support renewables, and distributed generation (DG) is also necessary. Some of the countries already have a high contribution from DG. Denmark has the highest rate (46%); while in Finland, it represents 32%; 28% in the Netherlands; and 21% in Austria.

The electrical interconnection between the EU and its neighbor countries is also a matter of concern with different treaties like the "Energy Community Treaty", signed in Athens on 25 October 2005, that boosts energy integration between EU and South East Europe (COM,2005b).

2.1.5 Energy Research

Member States have their own research policies and structures, which are usually efficient at national levels, but on a European level, this leads to fragmentation and inefficient use of resources. For the past two decades, the EU has had a policy of supporting science and technology aimed essentially at encouraging co-operation between European research players; this policy is directed through Framework Programs. To reinforce co-operation,

the Lisbon European Council adopted the European Research Area (ERA) in March 2000, thereby laying the foundation for a common science and technology policy across the EU (EU, 2002) as a common market for goods and services. The ERA is working to coordinate national research policies in the direction of shared objectives, expertise and resources.

All Member States and Associated States fund and perform research and technological development (RTD) activities related to non-nuclear research. However, there is an enormous variety between countries in levels of funding, evolving research priorities, and the way the research is implemented (EU, 2005b).

International co-operation is another weak point, both inside of the European community, and with other countries such as Japan or the US multilateral co-operation schemes for energy research are either provided by the EC, through the RTD Framework Programs² or the European Technology Platforms³ (ETP), or by the International Energy Agency (IEA), through implementing agreements.

Over the past two decades, this tradition of co-operation has received a massive boost from European treaties which have progressively incorporated common science and technology policy objectives. Actively encouraging cross-border co-operation since 1984, the Commission has launched a succession of multi-annual RTD framework programmes. Even if the budgets look small against the combined expenditure of all Member States together, the Union has contributed in this way to developing co-operation links in concrete, targeted projects in the key fields of medical, environmental, industrial and socio-economic research. Major support has also been given to researcher mobility, to SME participation in projects and to international scientific co-operation (ERAb).

2.2 United States

2.2.1 Resources

Ensuring electricity production in the US requires the availability of a range of fuels, some of them obtainable in the US and some of them imported. Electric power production in the US is mainly based on the use of fossil fuels. Coal and natural gas are the main sources, representing 52% and 13%, respectively, with oil representing 3%. Nuclear power is the second largest source representing 21%, and renewables count for 9%. The rest of the electricity production is represented by a small share of other sources (1%) and net energy imports (EIA, 2005a).

² See Section 3.1.

³ The ETPs are instruments of the EC that provide a framework for stakeholders, led by industry, to define research and development priorities, timeframes and action plans on a number of strategically important issues.

It can be said that the US is rich in natural resources for electricity production compared to the European case, including coal, natural gas, and oil (EIA, 2005b). Coal is mainly used for power production and almost all the consumption comes from indigenous production (EIA, 2005c).

The natural gas supply in the US is essentially a regional issue. The main producer is Texas, which produces 25% of the total, followed by Louisiana and Alaska (EIA, 2005f). Current policies for environmental protection are leading to an increase in fuel diversity, hence a forecasted large increase in natural gas consumption (EIA, 2005e).

Within the panorama of renewables, 74% of electricity production comes from conventional hydroelectric power stations, 9% is from waste, 8% from geothermal, 4% from wood, 4% from wind, and the rest from solar (EIA, 2005d).

2.2.2 Politico-Economic Context

The US is a constitutional federal republic comprising 50 states and one federal district. The federal government has three branches, namely the executive, legislative, and judicial branches. There is also a high autonomy at the state level, which allows each state government to develop its own regulations.

In recent years, the US has been affected by major incidents, in particular the September 11, 2001 terrorist attacks or in the case of energy policy, the August 14, 2003, widespread power blackouts of the Northeastern US and Southeastern Canada. After these incidents, security for the electrical supply became a matter of even greater concern.

Another relevant characteristic of the United States is the continual population and economic growth and corresponding growth in energy demand, as well as in the increase in the quality of the power demanded. Public awareness about the environmental cost of the increase in the energy consumption remains low.

2.2.3 Energy Policy

In the US, the Department of Energy (DOE) is in charge of energy matters; its decisions are supported by a cluster of independent agencies including the Federal Energy Regulatory Commission (FERC), the North American Electric Reliability Council (NERC), the Infrastructure Security and Energy Restoration (ISER), the National Association of Regulatory Utility Commissioners (NARUC) and the Energy Information Administration (EIA). The DOE does not have mandatory attributions but influences the legislative branch's activity.⁴

To improve the energy policy system, the Congress recently passed the Energy Policy Act of 2005 (EPAct,

⁴ FERC, for example, does have some authority to make rules at the inter-state level.

2005), which provides a set of rules and incentives to upgrade the system. The EPAct 2005 is the result of an integrated effort of the different stakeholders; the results represent the keystones in the US energy policy: energy security, power system reliability, competitive energy markets, investment in power infrastructure and environmental protection. This act is expected to change the energy policy situation (Kuhn, 2005) in the near future, by creating self-regulating institutions with mandatory attributions able to propose regulations concerning the power system at the federal level, i.e., Electric Reliability Organization (ERO) enforcing reliability rules with mandatory attributions; or granting new mandatory attributions to the existing ones, i.e., FERC receives the authority to approve the siting of electric transmission facilities located in specified areas.

A large portion of energy policy is defined and regulated at the state level in the US. In particular, regulations regarding energy market implementation correspond to the state level; therefore, the panorama in US energy markets is characterized by very different degrees of implementation in the different states (Rose, 2004).

2.2.4 Power Infrastructure

Despite the success of wholesale electricity markets in some regions, and the ability of new participants to address the nation's needs for new generation capacity, there is growing evidence that the US transmission system is under stress. Growth in electricity demand and new generation, lack of investment in new transmission facilities, and the incomplete transition to fully efficient and competitive wholesale markets (which in some regions are not embraced today) have allowed transmission bottlenecks to emerge. These bottlenecks increase electricity costs to consumers and increase the risks of blackouts (DOE, 2002). Another problem is the necessity of enlargement of the infrastructure; an indicator of this necessity can be found in the number of transactions (2397 in 2005) that could not be completed because of congestion on transmission lines (IRO-006-1; NERC, 2005). This limitation is restricting the access to less expensive power supply sources and also obstructing the development of competitive wholesale markets. Another problem is the aging of the power infrastructure; therefore, an increasing necessity of modernizing the power system (DOE, 2003).

2.2.5 Energy Research

The structure of energy research in the US is organized in two independent levels-federal and state-and also tied in with university research environments.

At the federal level, the DOE is in charge of the management of energy research. The DOE has two kinds of instruments, the DOE Offices for managing the different programs and assigning projects, and the National Laboratories, which maintain a staff of researchers in charge

of developing the assigned projects. To help improve and expand the electric delivery system, the DOE established the Office of Electricity Delivery and Energy Reliability (OE). By conducting research, development, modeling, and analysis, the OE provides solutions to problems facing the grid, ensuring system reliability.

At the state level, and depending on local governments, there are different energy agencies. A successful example is the California Energy Commission (CEC), which manages programs like the Public Interest Energy Research (PIER) Program for rational use of energy.

2.3 Comparison

Comparing the energy environments in the US and the EU helps elucidate the similarities and divergences in their views of future intelligent power grids. This comparison looks at: resources; energy markets; infrastructure weak points; environmental concerns; energy policy; and energy research mechanisms.

Reviewing the two cases, some conclusions can be extracted:

- The US is richer than Europe in resources (with petroleum as well as coal). That makes its policy more focused on clean coal technologies, which differs from the European policy focus on renewable sources and high efficiency DG technologies.
- Energy markets have relatively strong support in both environments, at nation or state levels as much as federal (or European) level. A difference between them is the more controlled way in which Europe is going about the deregulation and privatization process, setting up regulations like the 2003 EU Directive. Meanwhile, in the US, FERC currently lacks clear jurisdiction over reliability issues and NERC has only voluntary rules which have proven largely insufficient. The EPAct 2005 may change this situation.
- In the US, bottlenecks have been identified in the power grid, which complicates wholesale markets and creates stability problems. In Europe, the main concern is in the interconnection infrastructures between the countries. Although, after summer 2003, European and US electricity systems proved to be equally vulnerable to both transmission and generation problems.
- Another big concern in the US is security issues, including both blackouts and terrorist attacks. In Europe, a major concern is the growth of electrical infrastructures following very different patterns in the different countries.
- Environmental concerns in Europe are driven by its high commitment in matching the environmental targets of Kyoto, while in the US, efforts are driven by Environmental Protection Agency recommendations.
- Regarding energy policy, in Europe, the high support to the renewables, demand side management (DSM) and DG results in policy supporting the development

of these technologies, as well as the necessary reinforcement of transport and distribution capacity to support them and the reinforcement of the interconnection infrastructures between countries. Policy in the US is more focused on supporting coal clean technologies, with renewables, DSM and DG being a secondary focus.⁵

- Reliability in the transmission system in the US is addressed through preventive policy: disruption preparation and response. The EPAct 2005 calls for the creation of ERO that will enforce mandatory reliability rules for all stakeholders in the transmission system. In Europe, reliability in the transmission system is still being handled at national levels; European level policy supports the creation of the European energy market.
- The European Research Area aims to create a genuine “internal market” for research to increase pan-European co-operation and coordination of national research activities. In the US, energy research at both the federal and state levels is strong and well established.

2.4 Identifying Key Areas of Research

The analysis of the various issues above indicates that, in both worlds, there is a high necessity to increase research in a number of basic areas:

- Integration of DG and RES, as single units as well as microgrids.
- Standardization activities, e.g., in the interconnection of DG and RES.
- DSM, based on centralized or distributed intelligence.
- Development of market technologies (e.g., software platforms).
- Demand response technologies (e.g., enabling response to pricing, frequency or voltage signals).
- Socio-economical analysis targeting the development of pre-regulations.
- Laboratory testing in support of the different technologies.
- Pilot initiatives (e.g., demonstrating integrated electric and market operations).

Current research efforts related to these key areas are presented below, and the state-of-the-art and main contributions in each of the environments are discussed.

3. Direction of Related Energy Research

Energy research at the federal levels in Europe and the US has been performed following very different organizations. In the US, research is usually directed from the DOE’s offices by means of various programs and performed primarily by the national laboratories (and in

⁵ In the US, DG is seen as dirtier than central generation. In Europe with co-generation (like district heating systems and vast CHP systems), DG is not seen as dirty, so the concept is built in and people more willing to accept sacrifices.

collaborative programs between the national laboratories, industry, and academia). In Europe, research starts with an open call for proposals in determined areas. Relating to intelligent power grids, research at the European level focuses on the integration of RES and DG into European electricity networks, while in the US this research is spread across a number of programs.

The main programs and projects at the federal level in the US and at the European level in the EU are overviewed below. The last point compares the state-of-the-art of energy research in these areas in both worlds, which is a basis for the development of the two different visions of the future intelligent power grid.

3.1 Research at the European Level

Since 1984, research and innovation activities of the EU are enclosed in large programs called Frameworks Programmes (FP). The FPs delimit, focus, find and monitor research at the European level. FP objectives and actions vary from one four year funding period to another. The FP5 (1998–2002) project results relating to the intelligent power grid concept are presented below. (The results of FP6 (2002–2006) have not been published yet.) The projects performed under these two FPs formed the background knowledge that led to the definition of what in Europe is called the “smart power grid”, which will be reflected in the SmartGrid target area in the next FP. In FP7 (2007–2013), “Smart energy networks” will be one of the activities within the energy theme, and “Smart-Grid” is the name of the ETP. There are also other, not research-based, programs, outside the FPs, related to the application of new technologies and policies to the European energy system, such as Intelligent Energy Europe (EC, 2003a, b; IEEA).

3.1.1 FP5’s Target Action: Integration of RES and DG into European Electricity Networks

From the portfolio of projects of FP5, 50 are seen as the starting point for the development of the first generation of components and new architectures for interactive electricity grids, all of them belonging to the Integration of RES and DG into European Electricity Networks Target Action. Among them is the EU Cluster Integration of Renewable Energy Sources and Distributed Generation into the European Electricity Grid (IRED) (IRED Cluster), which gathered the efforts of 100 participants. More information about these projects can be found in EU (2005c). The results of these projects have been related to five main areas: increasing power quality (PQ), reliability and security; IT applied to the power grid; laboratory activities; pilot installations and field test; and preregulation activities in the transformation of the power grid.

3.1.1.1 Increasing PQ, Reliability and Security

Three examples of projects in this area are Microgrids, Dispower, and DGFACTS. The Microgrids projects (Mi-

crogrids_project), investigated a number of innovative technical solutions for microgrid operation and control, especially under islanded operation. The Dispower project (Dispower project) developed a PQ management algorithm able to solve voltage limit violations in low-voltage grids by optimizing control of generators, storage units and controllable loads. DGFACTS (DGFACTS project) investigated the development of new concepts for the management of the quality of DER-dominated networks, based on Flexible AC Transmission Systems (FACTS) and Custom Power Technologies.

3.1.1.2 Development of Market Technologies

Intelligence in the grid involves designing innovative hardware and software components for the electricity grid, in ways that cross-cut power and information and communication technologies (ICT) systems engineering, such as those involving software agents and electronic markets. An electronic market game, called Elektra, was developed in FP5 to enable people to experience how the concept works. Also, the European project CRISP (Crisp project) led to several innovative applications in developing agents, which are pieces of software that represent someone or something. They negotiate with other agents for the allocation of resources and communicate this to the controller software of the devices represented. The project studied the underlying principles defining electronic markets and provided automated means of technical coordination and optimization in systems with many diverse components. These agents are a basis for new forms of distributed control with global intelligence.

3.1.1.3 Laboratory Activities

A network of high-quality European DG laboratories was set up within the FP5 IRED Cluster. In FP6, this network was extended in the framework of a durable European Network of Excellence (NoE) entitled DER-Lab, which brings together a group of 11 organizations for the development of grid requirements and certification procedures for DG components. DER-Lab will act as a platform for the exchange of the current state of knowledge. The DER-Lab network will make significant contributions to European standardization activities and will contribute to the harmonization of the different national standards.

3.1.1.4 Pilot Installations and Field Tests.

One pilot installation in FP5 was a virtual power plant settlement in Stutensee, Germany. In Stutensee, around 400 people live in 100 apartments and row houses. The former energy system for the residential settlement was converted to a small virtual power plant. The generation units include: a co-generation plant (gas driven, 28 kW) with heat storage; several photovoltaic (PV) systems amounting to around 30 kWp; and a battery system (100 kW/h), acting both as supplier and load. The demand side is controlled by a near realtime energy market that sends

the information of minimal prices to the customers via cell-phone. A second test plant is the experimental Technology Demonstration Centre site, which was set up at San Agustin del Guadalix (Spain) to monitor and control impacts of DG for PQ improvements.

3.1.1.5 Pre-Regulation Activities

To optimize the large-scale integration of DG units in the European power grid, a regulatory roadmap was necessary. In elaborating this roadmap, the Sustelnet project (Sustelnet project) brought together a large number of stakeholders, such as electricity regulators, policy-makers, operators and supply companies, as well as representatives from other relevant institutions to debate the criteria for an optimal regulatory framework. These included sets of measures to be taken in different regulatory periods up to the year 2020. Also, ENIRDG-net (ENIRDG-net project) completed the assessment and overview of progress in EU Member States regarding policy and regulation for DER integration.

3.1.2 FP6 and FP7

Examples of projects in these two FPs include:

- FENIX (“Flexible Electricity Networks to Integrate the eXpected energy evolution”), a joint effort of 19 European institutions, aiming to conceptualize, design and demonstrate a technical architecture and commercial framework for Large-Scale Virtual Power Plant.
- MORE MICRO-GRIDS (“Advanced Architectures and Control Concepts for More Microgrids”) aims at increasing penetration of microgeneration in electrical networks through the use and extension of the Microgrids concept. This consortium includes major European manufacturers, power utilities and potential Microgrid operators and research teams with complementary expertise.
- DER-LAB (“Network of DER Laboratories and Pre-Standardisation”) brings together a group of 11 organizations for the development of grid requirements and certification procedures for DER components. DER-Lab will act as a platform for the exchange of the current state of knowledge between the different European institutes and other groups, contributing to the development of new concepts for the control and supervision of electricity supply and distribution and will bundle specific aspects concerning the integration of DG and RES technologies.

According to FP7 documents, “Smart energy networks” will be one of the activities within the Energy theme (EC, 2006a) and “SmartGrid” is the ETP which will bring together stakeholders, under industrial leadership, to define and implement a strategic research agenda, setting common research priorities in this area (EC, 2006b).

The initial objectives of this new activity area are to increase the efficiency, safety and reliability of the Euro-

pean electricity and gas system and networks, e.g. by transforming the current electricity grids into an interactive (customers/operators) service network, and to remove the technical obstacles to the large-scale deployment and effective integration of distributed and RES.

3.2 Research at the US Federal Level

Research in the field of power grids is developed, planned and analyzed by the DOE, currently led by the Office of Electricity Delivery and Energy Reliability (OE). Within the OE, the Electric Power Systems Research and Development Division manages a portfolio of projects to create “next generation” electric delivery technologies, and accelerate their introduction to the marketplace. This group works with other divisions and programs to understand the vulnerabilities and weaknesses of today’s grid and uses the information to develop better technology for the future. Primarily within the OE, key current programs focusing on the concept of future smart power grid are the Electric Distribution Program, the GridWise Program, the Transmission Reliability Program, and the Distributed Energy Program. The OE also has a Electric Markets Technical Assistance Program, which provides analysis and support for policies, market mechanisms, and programs that facilitate competitive, reliable, environmentally sensitive, customer-friendly electric markets, e.g., New England Demand Response Initiative (Coward and Raab, 2003).

3.2.1 Electric Distribution Program

The Electric Distribution Program (which refers collectively to the Electric Distribution Program and the GridWise Initiative) (EDT) aims to transform today’s electric distribution infrastructure through integration of advanced communications, information, sensors and controls, and DER with electric power systems. The Program develops standards for interconnection and system architecture; researches advanced technologies in sensing, communications, control, and power electronics; demonstrates integrated electric and market operations; and supports development of regulations that properly value electric services and DER.

The term GridWise is used by the Electric Distribution Program to denote “the operating principle of a modernized electric infrastructure framework where open but secure system architecture, communication techniques, and associated standards are used throughout the electric grid to provide value and choices to electricity consumers.” GridWise indicates also the vision of the future intelligent power grids in US and it will be described below.

One OE project in this area is the Olympic peninsula GridWise project (Coll et al., 2006), using GridWise technologies to address constraint in a distribution feeder. The solution proposed involved the development and implementation of new technologies as well adapting existing ones, using automatic response to prices as well

as under-frequency support in a real environment composed by a set of DG units, controllable loads and a near-real-time, with real-cash consequences, energy market.

The OE also supports standards development through the efforts of the GridWise Architecture Council and through support of specific areas such as supporting the Institute of Electrical and Electronics Engineers (IEEE) 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems and supporting the EPRI's IntelliGrid program.

3.2.2 Transmission Reliability Program

The Transmission Reliability Program's (TRP) mission is to develop technologies and policy options that will support grid reliability and efficient markets during the transition to competitive power markets. The TRP is developing advanced technologies, including information technologies, software programs, and reliability/analysis tools to support grid reliability and efficient markets during this critical transition. GridWorks is an OE program also related to transmission, which aims to improve the reliability of the electric system through the modernization of key grid components (cables and conductors, substations and protective systems, and power electronics).

One example of an OE project focusing on real-time grid reliability management is the Area Control Error (ACE)-Frequency RealTime Monitoring System. This tool will allow NERC reliability authorities to monitor compliance with rules that govern the reliable supply of electricity in real time and instantly pinpoint emerging violations. Other examples, in collaboration with the Consortium for Electric Reliability Technology Solutions (CERTS), are the Eastern Interconnect Phasor Project (EIPP) and the DER Integration research surrounding Microgrids (Lasserre and Piagi, 2004).

3.2.3 Distributed Energy Program

The Distributed Energy Program's (DEP) supports research and development aimed at lowering costs, reducing emissions, and improving reliability and performance to expand opportunities for the installation of distributed energy equipment today and in the future. Its activities are focused on distributed energy technologies (gas turbines, micro-turbines...) and integrated energy systems (CHP applications and technologies).

3.3. Comparison of Research in the Areas Identified

In general, the US research in this field is more dispersed across a variety of programs, while European research focuses on one target area. Comparing the research in both environments in the areas identified above, it can be concluded that:

- The integration of RES and DG has been more deeply developed in Europe than in the US. The whole target area in the FP5 program was called "Integration of

RES and DG into European Electricity Networks." The interest in this area is clearly derived from the lack of natural resources in Europe and the commitment of the EC to the Kyoto protocol.

- In standardization activities, both the US and Europe are focusing efforts through international standardization associations.
- DSM has been a research focus at the European Level, for example, with projects that include the study of buildings as thermal accumulators. In the US, recent research promoted at the federal level is more focused in the response technologies, such as frequency response, i.e., supporting the development of the Grid-Friendly™ appliances, inside the GridWise program. DSM research and programs in the US has been performed more at the state level, such as through the CEC's PIER Program. The EAct 2005 may result in an increase in demand response research (both at the federal and state levels) in the US.
- Although, development of competitive and reliable electric markets is a focus of both European and US policies (and, therefore, the development of technologies for those markets), market technologies such as software platforms are technologies mainly related to the industry, such as IBM or AREVA T & D. This research is supported by specific projects in both environments, for example, a GridWise demonstration project which applies IBM's market technology.
- Because technologies for enabling price responsiveness are necessary for implementing energy markets, they have been supported in both environments. Europe has extensive industry experience in energy programs at country levels, for example with time-of-use tariffs for electricity, and research has been more focused on using related technologies to control DG units. In the US, time-of-use tariffs are not widely implemented in industry, and research has been more focused on load control in industry as well as in households.
- In social-economic research supporting preregulation development, the research system in the US develops technologies that can often be applied directly in industry, while the research system in Europe also has to develop the network between the European countries to homogenize the research panorama, which sometimes leads to research that is less directly applicable. The result is that the social aspects take on more importance than economic aspects in the European research world, while the inverse is seen in the US.
- Laboratory testing is basic in the two environments. In the US, the DOE maintains a regular staff of researchers in laboratories across the country. In Europe, the EC supports collaboration and co-operation of a network of laboratories in different countries, called DER-lab.
- Complementing the research initiatives, in the US and

Europe, the application of research in pilot programs and test beds is encouraged and even compulsory in some cases. (In Europe, one selection criteria for obtaining project funding is that the project idea be applied in a test plant.)

4. Vision of Future: Intelligent Power Grids

Visions of a modern and future intelligent power grid are being developed simultaneously in the US and in Europe. In the US, the DOE's vision is called GridWise and in Europe, the EC's vision is called SmartGrid. Related concepts of the future intelligent power grid are also being pursued by other programs, which, although they may not be directly within the GridWise or SmartGrid umbrellas are likewise providing valuable contributions in this field (e.g., led by EPRI, CERTS, CEC).

The two visions, GridWise and SmartGrid, are presented and compared below.

4.1 European Vision: SmartGrid

SmartGrid is the name of the ETP (ETP SmartGrid) that deals with the "Vision and Strategy for Europe's Electricity Networks of the Future." The initial concept and guiding principles of the SmartGrid Technology Platform were developed by the Directorate General for Research (DG-RTD) with the support of an existing FP5+6 research cluster (IRED), which represents over 100 stakeholders in the electricity networks sector.

SmartGrid aims to achieve flexible, accessible, reliable and economic future electricity networks for Europe:

- Flexible, fulfilling the needs of all the customers.
- Accessible, granting access to electric assets to all applicants, particularly for RES and high efficiency local generation.
- Reliable, assuring and improving security and quality of supply.
- Economic, providing the best value through innovation, efficient energy management and a level playing field.

This vision will be achieved by transforming the current electricity grids into an interactive (customers/operators) service network, and by removing the technical obstacles to large-scale deployment and effective integration of distributed and RES.

Summarizing, the SmartGrid is a ETP led by the European stakeholders in this area (transmission and distribution system operators, regulators, etc.) and facilitated by the Member State representatives and EC-DG RTD. SmartGrid represents the European vision of future power grids, with the objective of providing Europe with a flexible, accessible, reliable and economic electricity network by using IT technologies, and an efficient energy market as well as a complete integration of DGs.

4.2 US Vision: GridWise

The term GridWise denotes the operating principle of a modernized electric infrastructure framework where open

but secure system architecture, communication techniques, and associated standards are used throughout the electric grid to provide value and choices to electricity consumers. The GridWise vision can also be described as seeking to modernize the Nation's electric system from customer appliances and equipment to generation and create a collaborative network filled with information and abundant market-based opportunities. This vision evokes concepts of seamless plug-and-play technologies and a "society" of devices, while recognizing the need to integrate with and evolve with the extensive, existing traditional infrastructure for secure, reliable and affordable energy. In particular, GridWise introduces the notion of a "transactive" system, integrating market-based transactions with control methods, in a complex, distributed, physical system of intelligent devices.

Summarizing, GridWise is an initiative framed in the Electric Distribution Program of the DOE, and shared by an increasing array of stakeholders, which represents the US vision of future power grids. The objective of this vision is to provide the US with a secure, reliable and affordable electricity network using new IT technologies and efficient market mechanisms.

4.3 Comparing the Two Visions

The similarities between these two visions are obvious, both of them are based on integrating new information and communications technologies, combining them with active support from electricity consumers, and leveraging the optimizing power of markets, to focus on creating an affordable and reliable power grid. Some differences between the two visions stem from the different contexts in the US and Europe.

Europe's vision is clearly influenced by the concern derived from the wide range of natures and degrees of evolution of the power grids across European countries. The consequence of this concern is identified in the need to have a 'flexible, reliable and accessible power grid', which basically means a power grid that can fulfill the needs of a wide range of customers and economies. This fact, and the lack of indigenous resources, results in Europe's emphasis on a distributed grid, where large amounts of DG, RES and loads are controlled by an energy market, the grid flows are bidirectional, and the demand response is automatic. These DG units can be directly connected to the main grid but are also viewed as forming clusters of minigrids.

The vision in the US is marked by the perceived necessity for increasing security and responding to the predicted growth in the demand. The US expects to use information technology to increase the use of assets and, therefore, reduce the pressure to increase investment. More so than in Europe, the vision proposed in the US is mainly related to what is still seen as a largely centralized power grid (with unidirectional fluxes based on, for

example, coal technologies) but with a high integration of demand response technologies and some penetration of DG used for additional support to the system, all controlled by various markets.

Therefore, the visions in the two worlds differ mainly in conception of the generation. Europe is more focused on creating a highly distributed environment, with a large penetration of RES and DG, while the US envisions large power stations based on clean coal technologies as the basis of the system, where the inclusion of DG is perceived primarily as an increment in the security of the system not as the basis. On the demand side, the visions of both worlds coincide, ultimately targeting automatic demand response controlled by real-time markets, although the intermediate paths they may pursue to move toward this target are varied.

5. Analysis of Opportunities

After analyzing the contexts and visions in the US and Europe, it is encouraging that the research being done in both environments is not only compatible, but could also be complementary.

This section presents the research areas of both initiatives, GridWise and SmartGrid, and identifies opportunities for collaboration, with a remainder of the precedence for and desirability of such trans-Atlantic collaboration.

5.1 Research Areas in the Future SmartGrid Initiative

The main research areas in the future SmartGrid portion of the EC's FP7 can be summarized as:

Intelligent networks: This area includes the development of new concepts, system architectures and a regulatory framework for control, supervision and operation of electricity networks to transform the grid into an interactive (customers/operators) service network, while maximizing reliability, PQ, efficiency and security. These systems should be based on applications of distributed intelligence, plug and play, e-trading, power-line communications, etc.

Efficient DG technologies: This area strives to reinforce and balance efforts made towards the development of DG.

DSM and demand response techniques: In this area the target is the development of customerside energy management systems capable of managing local power consumption and redispatching local loads to take full advantage of real-time energy prices and network status information. **New energy services:** This area is promoting the development of new energy services, such as remote metering, remote control of appliances, real-time monitoring of homes to enable better care for the elderly and other vulnerable groups, etc.

Improving the efficiency of power transmission and distribution: This area is to developing technologies such as high voltage direct current (HVDC), advanced high-temperature cables, high-efficiency transformers, etc.

Enabling technologies: This area aims to bring low-cost technologies to the market to bridge between local networks and create a modern pan-European network with the capability of integrating significant DER.

Stationary energy storage: This area focuses on energy storage technologies including advanced solutions for batteries, flywheels, superconducting magnetic energy storage, compressed air energy storage, and super capacitors.

5.2 Research Areas in the GridWise Initiative

In the GridWise initiative the following areas for research work have been identified:

Communications architecture and standards: This area is developing the architectural framework and related standards needed to share information and form an interoperable network from generators, through transmission and distribution, to consumers.

Simulation and analysis tools: While promising, many of the concepts surrounding complex markets and energy systems have not been fully explored or tested. Tools to simulate energy markets and energy systems will combine operations and economics in a single model to analyze and assess the system as changes are implemented to determine the impacts and ensure fairness.

Smart technologies from the Government and industry: While industry will invest in technologies seen as potential profit-makers, the federal program will help seed the early development of technologies that individual commercial companies otherwise might not risk pursuing to help jump-start the transformation.

Test beds and demonstration projects: This area supports test beds and demonstration projects, providing experiments of ever increasing scale to prove the worth of these technologies or reveal their faults. They will help build acceptance of the concept of a transformed energy grid and reduce the perception of risk.

New regulatory, institutional and market frameworks: This area will develop the framework necessary for supporting a climate of innovation as these technologies are developed.

5.3 Linking Priority Areas in Both Initiatives

GridWise and SmartGrid initiatives are not subdivided along the same lines, but correspondences between their research areas are identified in Table 1 below.

5.4 Identifying Opportunities for Collaboration

Some examples of opportunities for collaboration between SmartGrid and GridWise are described below.

The areas offering more interest for direct collabora-

Table 1. Linking priority areas in SmartGrid and GridWise

Priority areas in SmartGrid	Priority areas in GridWise
Intelligent networks	Communications architecture and standards
Efficient DG technologies	New regulatory, institutional and market frameworks
Not defined as a research priority	Not defined as a research priority, some aspects included in smart technologies and test bed areas
DSM and demand–response resource techniques Enabling technologies	Simulation tools for energy markets
New energy services (remote control of appliances)	Smart technologies from the Government and industry
Implicit in other areas, through test bed requirements	Test beds and demonstration projects
New energy services (remote metering)	Within both GridWise and GridWorks (GridWorks) program and other programs
Improving the efficiency of power transmission and distribution	
Stationary energy storage	
Similar linkages could also be drawn between SmartGrid and state-level programs such as the CEC PIER program.	

tion (i.e., efforts with potential for working jointly toward common goals) are system architecture development; the development of standards; development of the DSM and DR techniques; enabling technologies; and parts of the new energy services (e.g., regarding remote control of appliances, remote and advanced metering, etc.). A second type of collaboration, called collaborative exchange below, encompasses points oriented toward the exchange and sharing of knowledge such as surrounding DG integration, simulation tools development and regulatory frameworks.

Areas for direct collaboration:

- GridWise and SmartGrid can work together to support and develop an interoperability framework and related standards in conjunction with international standards organizations, such as the IEEE or the International Electrotechnical Commission (IEC).
- The DSM and DR techniques area is suitable for combining research efforts in co-coordinated projects, developing common techniques while implementing them in both environments to compare their performance. Therefore, the collaboration proposed here could be to join in a common research project or test bed activity.
- The development of enabling technologies is another potential field of collaboration, where most of the research should be led by industry and supported in some cases by governmental programs. The collaboration in this field could be to manage common programs which could support joining efforts of industry on both sides of the Atlantic.
- New energy services is an area which involves not only GridWise program but also other programs such as GridWorks. One part of this area related to GridWise is the development of technologies such as remote control of appliances responding to inputs like prices or frequency. Collaboration in this case, with close ties to industry, would be similar to the development of enabling technologies.

The collaborative exchanges proposed:

- System architecture development offers the opportunity of sharing knowledge of the alternatives proposed by every team. The proposed collaboration in this case would be the organization of workshops, where the teams involved could present the different ideas and projects being developed.
- DG integration, as shown above, is a priority in the European environment, although not in the US environment. This makes the research in Europe more focused on this point than in US. Therefore, in this case a suitable activity would be the organization of seminars, led by the European research.
- The development of simulation tools is a cornerstone in the GridWise program and not in the SmartGrid initiative. The activity proposed would be the organization of seminars led by the US.
- The regulatory framework development is different for both initiatives, although an interesting collaboration would be to organize workshops in order to exchange information about the advances in each case.

Direct collaboration relates to areas where the two teams can work jointly, collaborative exchange relates to areas where they can learn from each other’s experiences. In direct collaboration, activities such as co-coordinated projects have been suggested in areas related to development of architectures, standards and technologies. Collaborative exchange would involve activities focused on the exchange of information such as workshops and seminars and could cover any of the research areas of the two programs, but particularly in DG and simulation.

5.5 Trans-Atlantic Collaboration: Reasons and Precedence

The obvious advantages of collaborating are to avoid duplicity in research and to develop standardized technologies that can serve broader markets and more rapidly leverage international standards mechanisms. A solid precedence for such energy research collaboration exists already in fields such as fuel cell research and nuclear energy research, within the legal umbrella of the

Agreement for Scientific and Technological Co-operation.

The framework for non-nuclear energy scientific and technological co-operation between the EU and the US was defined by the implementing agreement between the DOE in Brussels in 2001 (EU, 2001). Signed by the Secretary of Energy of the US government (Mr. Spencer Abraham) and by the Commissioner for Research of the EC (Mr. Philippe Busquin), this document proposes different forms of collaboration involving:

- developing joint standards,
- sharing unique R&D facilities,
- workshops,
- exchanging and networking experts, and
- conducting joint technology foresight studies, and co-coordinating research projects.

In October 2004, the US and the EU signed a five-year renewal of their Agreement for Scientific and Technological Co-operation, which serves as legal umbrella for undertaking co-operative research in a number of fields, including non-nuclear energy.

One example of collaboration in non-nuclear energy is the case of the fuel-cells, opening the International Partnership for the Hydrogen Economy to bring together the United States, the European Community and 15 countries in collaborative research to overcome technological roadblocks to the hydrogen economy. Another example of a successful international co-operation is the CERN (European particles physics laboratory), considered a center of excellence in the EU and working with the participation of the US and Japan.

After President Bush's visit to Europe in 2005, the following declaration from EC President Barroso was published:

The visit of President Bush is really a very, very important one. Europe and America have reconnected. This visit has highlighted all that unites Europe and America; it has focused the eyes of the world on all that we share. I believe that the relationship between the United States and Europe is the world's strongest, most comprehensive and strategically important partnership. The United States, a united Europe, this is really the indispensable partnership.

This declaration sums up the positive attitude of the two worlds toward collaboration-an attitude that should clearly be extended to address the realm of future intelligent power grids.

6. Conclusions

This paper has reviewed the situation in the field of intelligent power grids in the EU and in the US and has compared and analyzed the vision of the future in both worlds. Examining these two pictures side by side reveals surprising similarities between both the research needs and the research topics under investigation, despite

very different contexts and research program organizations. The last point of this paper analyzed and suggested a number of general areas where collaboration between the US and Europe would avoid duplication in research and provide opportunities for beneficial exchange.

The time is right for policy-makers and decisionmakers to actively enable and pursue opportunities for joint activities between the GridWise in the US and SmartGrid in Europe.

7. Acknowledgments

The authors wish to thank the US Department of Energy and Pacific Northwest National Laboratory (PNNL) for their support through the GridWise Program, and the Physics Department of the University of Balearic Islands (UIB) for promoting and supporting the co-operation between research institutions. We would like especially to thank Eric Lightner and Prof. Juergen Schmid for creating the opportunity for this transatlantic exchange, Manuel Sanchez-Jimenez for his constant feedback, Rob Pratt and Dave Chassin among others for their constant feedback, and Todd Samuel for supporting this work. We would also thank the European Commission Directorate of Research for their input and support to this work. We look forward to the next major step in exchange between European and US research environments to take place at the Second International Conference on Integration of Renewable and Distributed Energy Resources at Napa Valley, CA, in December 2006.

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