April 2015

T&D Case Book

Version 1.0

SPOTLIGHT ON SMART AND STRONG POWER T&D INFRASTRUCTURE

INTERNATIONAL SMART GRID ACTION NETWORK

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MESSAGE FROM THE CHAIR

The energy systems of most countries are undergoing a very rapid evolution. The reasons for these changes are found in several domains, in particular the (1) increasing consciousness of the importance of reducing greenhouse gas emissions and mitigating the effects of climate change, (2) necessity of adopting all means of increasing energy efficiency and reducing energy consumption, (3) devastating financial crisis undermining the societal models progressively constructed in the last century and (4) geopolitical events changing the shape of countries and their mutual relations.

These drivers reverberate across the energy system and have triggered two important opportunities: the rapid deployment of renewable energy sources and the increasing need to empower local resources and responsibilities. Wind generation is being used in several countries as a major renewable energy source—mostly connected at the transmission level—and is contributing an important share of the energy mix. At the same time, solar photovoltaic is gaining importance as a distributed source of energy. New technologies and approaches for managing the load are also being developed, unleashing potential new roles and business models that allow local users to become actors in the energy system. Under these circumstances, we have variable and partly uncontrollable generation on one side, and a potentially higher level of load control and flexibility on the other side. Consequently, the design, management and control of the electricity networks are changing, requiring stronger and smarter networks to maintain the continuous, delicate equilibrium between generation and load that prevents instability and blackouts.

Although based on a similar holistic view of smart and strong electricity networks, the smart grid solutions to be used in different countries are inherently varied because they must be adapted to local conditions, infrastructure and policies. In this context, international collaboration and knowledge exchange are essential for leveraging resources and avoiding duplication of efforts. ISGAN, as an initiative of the Clean Energy Ministerial, has the explicit role of contributing to the exchange of experiences among its 25 participating countries.

This case book, prepared by ISGAN Annex 6 (Power T&D System), is the first step of a comprehensive process of surveying, analysing and discussing important achievements in the application of smart grid approaches. This process will provide valuable findings to guide and inform all parties interested in this field. This case book highlights real applications of smart grid approaches and technologies for the transmission and distribution domains in seven countries. It also describes and discusses lessons learned from the application of HVDC technologies, wide area monitoring and smart substations. In the distribution field, the case book addresses measures to maximise the hosting capacity of variable renewables and to integrate the response of users toward the application of flexible tariffs. Additional projects will be added progressively in future editions of the case book, and an online version will be developed.

I would like to express my sincere thanks to the coordination team of Annex 6, with special reference to Bo Normark, Susanne Ackeby and Carl Ohlen from Sweden. Special tribute must also be paid to the national experts from Ireland, Sweden, the United States, Italy, South Africa, France and Austria for providing data, information and insight. Thanks to their efforts, this case book represents a valuable reference for the deployment of smart and strong electricity grids. Enjoy the reading!

Michele de Nigris

CONTENTS

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INTRODUCTION

Spotlight on a Smart and Strong T&D System

New Challenges Require a Smart and Strong Power Infrastructure

Transmission and Distribution (T&D) systems face many new challenges. Increased variability in generation, which may produce large and unpredictable fluctuations in the power balance as well as variations in voltage, may jeopardize the quality and availability of power. Conventional T&D systems were not designed to accommodate variable generation from renewable energy sources (RES), a share that is progressively increasing in the generation energy mix. A move towards distributed generation, including solar photovoltaic (PV), further complicates electricity T&D systems. In addition to changing generation sources, changing demand patterns are being introduced through new types of loads, such as electric vehicles, and increased deployment of energy efficient technologies, such as efficient appliances and lighting. Increasing electrification of the heating sector, through the use of efficient heat pumps, will also likely increase variation in load.

The T&D system has to be smarter and stronger to provide the real-time flexibility needed to efficiently handle the new conditions. Investments in smart and strong T&D systems are essential to enable an efficient global clean energy society. T&D system investment needs are large and require long-term planning and deployment. Considerations include more efficient solutions with lower environmental impacts to address the environmental concerns and public acceptance issues that often arise when constructing additional conventional transmission lines.

The increased electrification and growing complexity of supply and demand requires a holistic system approach for power T&D development, for the following three reasons:

- The electrical system must balance supply and demand to maintain voltage and frequency within strict limits. This requires increased knowledge and supervision of system behaviour and wide-area implementation of information and communication technology (ICT) for monitoring, protection, control, automation, and visualization. It also requires increased flexibility from power electronics, such as flexible alternating current transmission systems (FACTS) and high-voltage direct current (HVDC).
- The increased share of total installed power from variable RES complicates power system operation by introducing less predictable and rapidly fluctuating conditions, that require instantaneous system-wide compensation and balancing of frequency and voltage.
- Additional distributed generation integrated through small-scale solar, wind, and hydropower; and greater customer participation in production through demand response (sometimes in combination known as "prosumers"), substantially increase the interaction among T&D systems.

Countries around the world have different challenges, will use different solutions to those challenges, and have reached different maturity levels in the implementation of those solutions. Smart grid solutions are found across the entire electrical system, from the high-voltage transmission grid through the distribution grid and at the consumer level. This casebook shares experiences from seven countries and from different levels in the electrical system. Although conditions vary among countries, there is significant common ground for sharing experiences.

Increased Digitalization

A holistic system will require even more advanced, accurate, and fast applications. Within a sound business management system (BMS), supervisory control and data acquisition (SCADA), and other Network Information Systems (NIS), will improve and automate management of energy, assets, distribution and demand-side activities, and substations. This complex interdependence, illustrated in Figure 1, raises the urgent need for interoperability among different components and "systems of systems" from diverse vendors that need to communicate with each other.

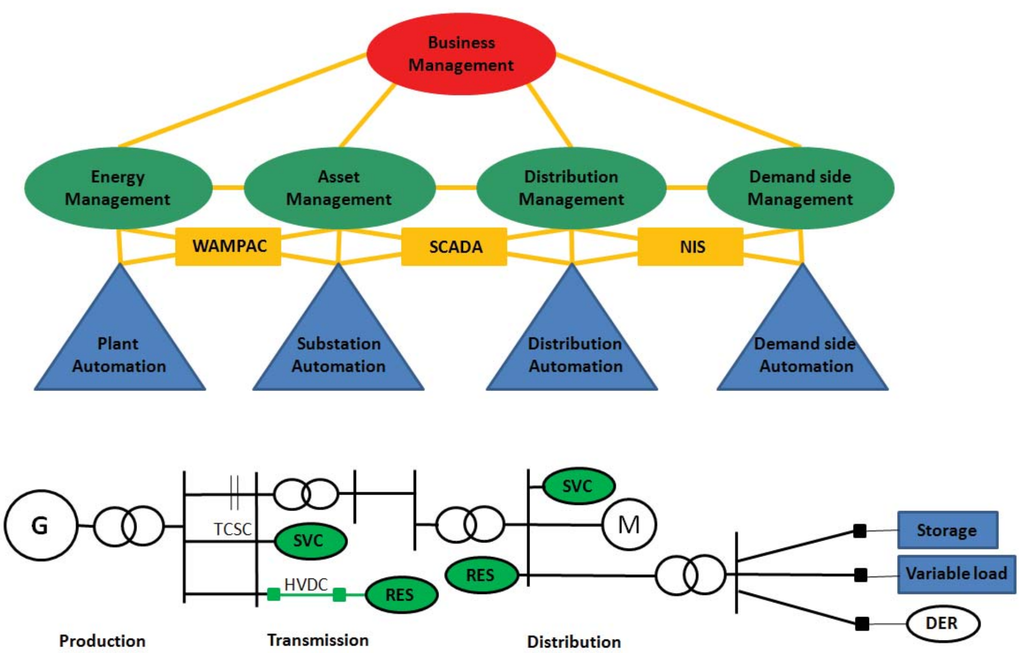

Figure 1: Illustration of the information interdependencies of the power system.

A description of the development of fully digital substations based on international standard IEC 61850 is given in the French case on page 72.

INTRODUCTION

Smart Transmission Grids

Making the grid smarter and stronger requires new solutions for all levels of the electrical system. The main mechanism to make the power system more flexible is to allow for faster changes in power flow. For more than one hundred years, the power system has been an analog system, consisting of bundles of copper wires and clicking contacts using alternating current (AC), normally at 50 or 60 Hz frequency. Even if direct current (DC) was used for local control in the substation, the systems still used analog technologies. Communication has also been mainly analog, even if a power line carrier and radio used higher frequencies.

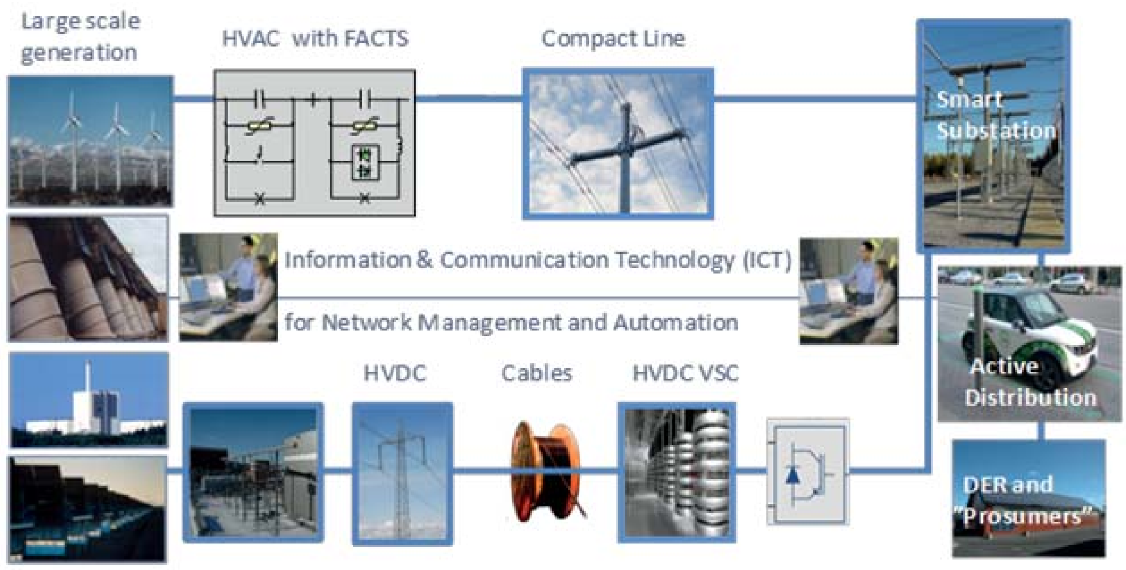

Figure 2. The electrical system is increasingly integrated with information and communication technology.

Analog technologies still dominate the power system and domestic (home) systems, but the last two to three decades have seen digital technology spread to almost every aspect of our life. This digital evolution provides the power system with new and better solutions. Power system management and automation with faster communication of greater quantities of data, and high-voltage technology with the development of power electronics for FACTS and HVDC, are benefits seen from the conversion of analog to digital signals. Power electronics for high-voltage alternating current (HVAC) and HVDC transmission, in combination with faster and more accurate ICT, form the core for the design and operation of a smarter and stronger grid.

Descriptions of the application of HVDC technology can be found in the Irish case (page 16) and also the Swedish case (page 26). The Swedish case describes the combination of different transmission technologies: overhead lines (OHL), underground cables, HVDC, and HVAC.

One further key aspect of smart grids is improved functionality for collecting and presenting data about the grid. Smart grids have improved forecasting tools, including wide area measurement systems (WAMS).

WAMS are described in the United States' case (page 36) and in the Italian case on page 48. Another possibility to improve network operation is achieved by increasing situational awareness, which has been done in South Africa and is described on page 60.

A separate chapter discusses the global deployment of HVAC and HVDC transmission solutions, including high voltage technologies (HVT) and ICT. This chapter begins on page 9.

Smart Distribution Grids

The distribution grid has traditionally been built with conventional technologies that offer lower cost and greater reliability. However, the changes described in the energy system demand new solutions that enable efficient means of meeting the new challenges, without compromising reliability or resulting in high costs. Increased controllability and new market models will create opportunities to solve these challenges. Tests and implementation of smart functionality in the distribution grid have demonstrated increased capability to ensure safe operation of the grid closer to physical capability limits and increased hosting capacity for renewable electricity production, without the need for investments in new primary infrastructure.

Examples of projects focused on increasing the hosting capacity in distribution networks are given in the Austrian case on page 82.

The smart grid concept includes increased participation of customers in the power system. Participation empowers customers that have access to their own production, which increases the use of renewables in the grid's generation pool and also enables different mechanisms to change the customer load profile. A smoother load profile improves the efficiency of the system. One way this could be achieved is by using the market and new tariff structures, such as Time-of-Use (ToU) tariffs, which have been demonstrated to be effective in shifting the load profile. However, the active participation of customers is a very wide area of opportunity, where much more can be done with even more sophisticated models.

The Italian case on page 94 describes the introduction of ToU tariffs and their effects on the system.

INTRODUCTION

Integrated Energy Systems

Smart T&D systems have demonstrated significant benefits, providing alternative solutions for meeting the new challenges facing the grid. In the coming years, smart T&D systems will incorporate other applications, including heat and electrical systems, stor age and electrical vehicles. Figure 3, featured in the International Energy Agency's (IEA's) *Energy Technology Perspectives 2014*, provides an illustration of the overall picture. A future casebook will expand the discussion to cover all of these areas.

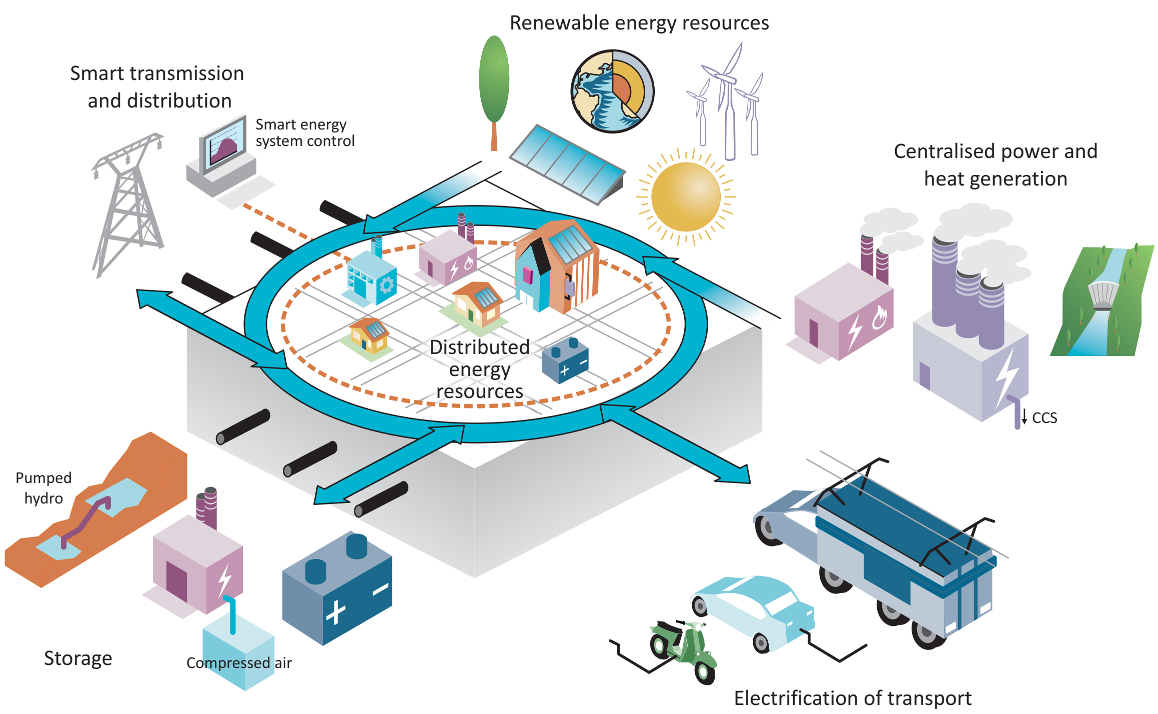

Figure 3. A sustainable electrical system is a smarter, multidirectional, and integrated energy system that requires long-term planning for service delivery.

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Important Lessons

The purpose of this casebook is to illustrate lessons learned and highlight a wide range of applications related to power T&D systems or smart grids. The examples are intended to support the value that smart grid solutions can offer in order to integrate renewable energy, improve the market, activate customers, and increase the security of the generation supply.

The following examples, chosen from various countries and addressing several technologies, offer a variety of lessons learned:

- United States: Synchrophasors increase power transmission in existing transmission infrastructure, allowing the introduction of more renewable energy, and increasing the reliability of electricity delivery.

- Sweden: HVDC advanced voltage source converter (HVDC-VSC) technology increases transmission capacity and helps avoid voltage collapse in the grid. AC and DC overhead and underground cables are combined to upgrade the capacity in existing transmission corridors to minimize the environmental impacts.

- Ireland: HVDC-VSC technology is used to build a combined submarine and underground interconnector, linking two electricity markets and thereby decreasing electricity prices and increasing the security of supply. The project provides a good illustration of community involvement, simultaneously increasing the acceptance of the project and youth interest in engineering.

- Austria: Smart solutions in the distribution grid increase the hosting capacity for distributed energy resources, including renewable electricity production, other types of distributed generation, demand response, and electric vehicles. The case illustrates that greater capacity can be created without adding primary infrastructure.

- France: Smart substations demonstrate how electrical equipment could safely operate closer to physical limits, thereby minimizing attendant investments in equipment improvements. At the same time, functionality has increased with enhanced monitoring and diagnostics. New sensor technologies improve operation and maintenance of equipment.

- South Africa: A new visualization system reduces down time and improves operation, maintenance planning and fault-location.

- Italy: Time-based tariff systems (i.e. ToU tariffs) increase customer involvement and improve the efficiency of the system by balancing peak and off-peak consumption to better fit with the availability of power. Several proposed applications may further improve the systems. In addition, WAMS technology improved the operation of the transmission system by better tracking of system stress and dynamic phenomena that potentially could lead to system disturbances.

INTRODUCTION

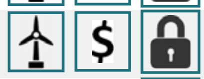
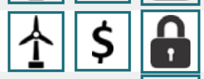
Casebook Structure

The case studies in this book illustrate a generic spectrum of solutions and range of technologies deployed to improve the strength and resilience of the grid and further realize the promise of a truly “smart” grid. Although countries share many similarities, the needs and ultimate solutions necessarily vary. The International Smart Grid Action Network (ISGAN) member community has therefore contributed these projects to illustrate applications, solutions, and technologies. This casebook includes both transmission and distribution projects, selected to be geographically diverse and to illustrate the following key drivers for building a smart electrical grid:

- Integrate renewables (R)
- Improve markets (M)
- Engage customers (C)
- Increase security supply (S)

Each case is structured to provide a general synopsis of the project by describing project objectives and benefits, technology used, results, and lessons learned.)

Version 1.0 covers a range of examples, in summary:

Country:	Case:	Level:	Reason:
Ireland	East-West HVDC Interconnector	TSO	
Sweden	Embedded HVDC link	TSO	
United States	Wide Area Reliability	TSO	
Italy	WAMS experience in Italy	TSO	
South Africa	Demand Response	TSO	
France	Smart Substation	TSO + DSO	
Austria	Active Distribution Network	DSO	
Italy	Customers' response under time-dependent electricity prices	DSO	

Of course there are many examples of good smart grid projects that cover the levels of transmission system operator (TSO) and distribution system operator (DSO) from all over the world that are not covered in this casebook. A number of these are mentioned in Chapter 11: "Related Projects" (page 106). The goal of this casebook is to be an evolving document that is periodically updated with new and aligned projects, focusing on both transmission and distribution.

GLOBAL TECHNOLOGY DEPLOYMENT

The global deployment of HVT and ICT is summarized below. Examples of high-voltage direct current (HVDC) include voltage source converter HVDC (HVDC-VSC), as well as interoperability standards for ICT (e.g., IEC 61850) and the deployment of phasor measurement units (PMUs) for wide-area monitoring protection and control (WAMPAC).

This chapter expands on ISGAN Annex 6 discussion papers and technology briefs (available online: http://www.iea-isgan.org/index.php?r=home&c=5/378), focusing on application of new technology) and solutions for "enhanced capacity, quality, flexibility and efficiency of power delivery," especially

- Technology Brief: "THE SMART AND STRONG GRID: Connecting Clean Energy with People"
- Discussion Paper: "SMARTER & STRONGER POWER TRANSMISSION: Review of Feasible Technologies for Enhanced Capacity and Flexibility"
- Discussion Paper: "FLEXIBLE POWER DELIVERY SYSTEMS: An Overview of Policies and Regulations and Expansion Planning and Market Analysis for the United States and Europe"

The above work is based on a number of international workshops, publications, and input from experts and organizations, including the International Electrotechnical Commission (IEC), the Council on Large Electric Systems (CIGRE), the European Network of Transmission System Operators for Electricity (ENTSO-E), the Global Smart Grid Federation (GSGF), the European Distribution System Operators' Association (EDSO), GO15, and other initiatives.

Global Deployment of HVDC

Since 2000, a large increase in HVDC installations has been driven by a combination of new markets and applications and new technology development. "Classic" HVDC with thyristors has been developed for ultra-HVDC (UHVDC; +/-800 kV) capable of more than 6,000 MW per transmission line, while HVDC-VSC with transistors (originally used for 500 MW) is being developed for higher voltages for converters and cables. HVDC-VSC can already provide a capacity of more than 1,000 MW per system, and with further development is expected to reach even greater capacity, especially for overhead lines.

The recent increase in HVDC, as well as the planned future projects, has been driven by three main applications:

- Large-scale and long-distance transmission of hydropower; primarily in China, India, and Brazil
- Integration of offshore wind power; primarily in northern Europe and planned for in North America
- Trading interconnectors; primarily subsea in Europe and some North American applications

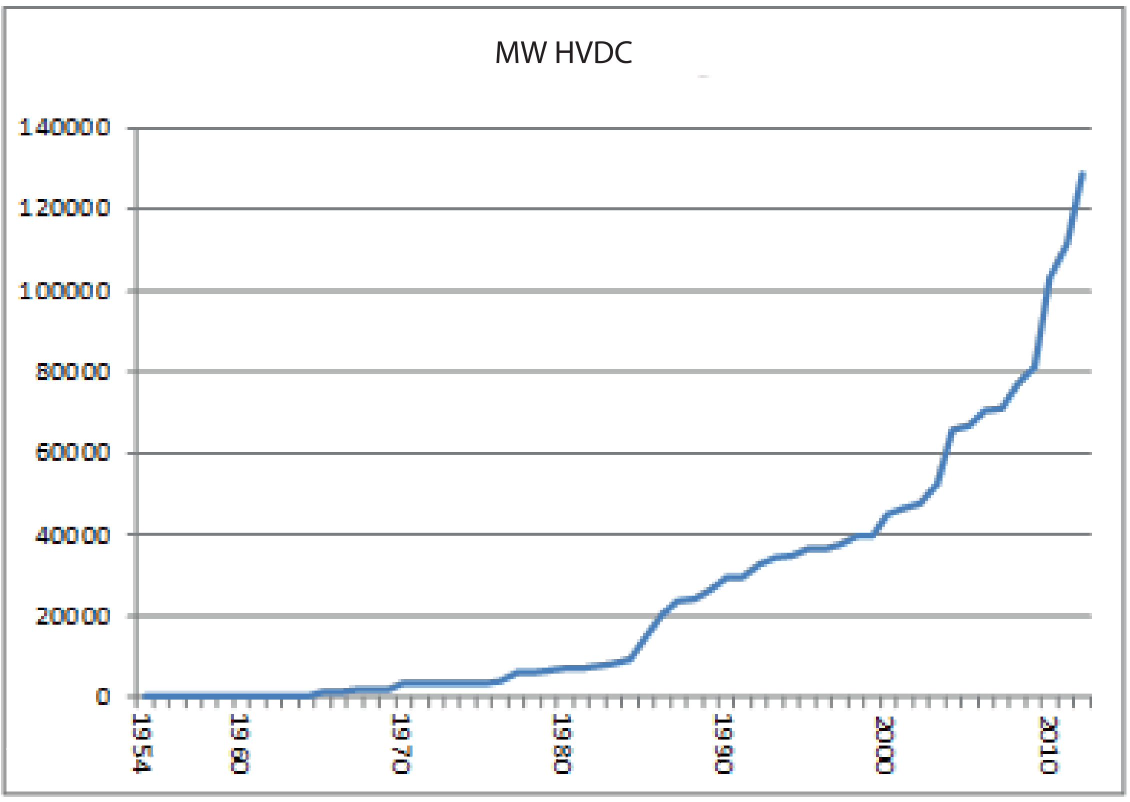


Figure 4: Global installations of HVDC.

Figure 4 shows the accumulated installed effect of HVDC systems in the world, which is also shown in Figure 5. Figure 5 presents the data divided into regions.

A revolutionary development in HVDC technology—high-power insulated gate bipolar transistors (IGBT)—made VSC-based DC transmission system possible. The first pilot system was built in 1997, and ABB completed the first commercial installation. Other manufacturers now offer this technology, although the majority of systems in operation are by ABB. The concept has been further developed for higher voltages and lower losses, and several projects are under execution by ABB, Alstom Grid, and Siemens, including several offshore wind projects for the TSO Tennet.

Figure 5 presents regional installations of HVDC:

Region:	MW to 2000:	Percent:	MW to 2012:	Percent:
EUR	6737	14%	12427	9%
North America	16142	34%	29482	22%
South America	7575	16%	13125	10%
China	3050	6%	49260	37%
India	5100	11%	13600	10%
Other	8600	18%	14610	11%
ALL[1]	47202	100%	132504	100%

Figure 5: Regional installations of HVDC.

[1] Some of the older plants have been dismantled or replaced resulting in an estimate installed base 2012 of 120,000 MWi

HVDC-VSC has many additional and “smarter” features and advantages compared to classic HVDC. It can rapidly control the power flow as well as the voltage, offering unique flexibility. Initially, HVDC-VSC was not intended for bulk power transmission but could be used in many other applications. It is therefore not fair to just compare MW to MW between classic HVDC and HVDC-VSC, because HVDC-VSC is often used for low or moderate transmission capacity.

The HVDC-VSC technology with transistors can be used for all applications, including subsea and underground cable applications with cross-linked polyethylene (XLPE) extruded cables, but has seen particularly extensive use in the following applications:

- Offshore applications (e.g., wind, wave, and oil platforms)
- As an alternative to AC and classic HVDC
- Embedded HVDC within AC power system
- DC grids (offshore and onshore)

Global Deployment of IEC 61850 and PMU

ICTs monitor, protect, and control the power system. These technologies have developed over the course of more than 100 years from electromechanical devices, to static devices, to fully digital microprocessor-based intelligent electronic devices (IEDs). In the same manner, communication lines have evolved from bundles of copper wires to fibre optic cables.

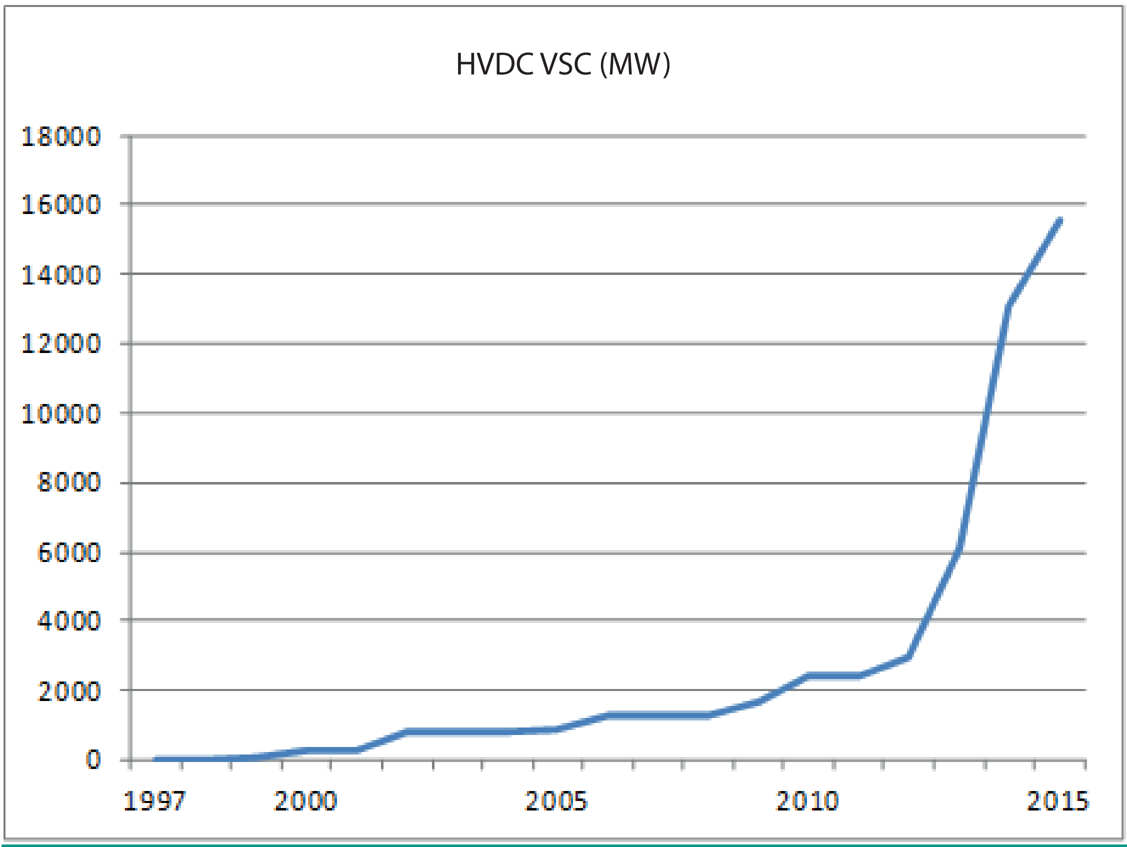


Figure 6: HVDC VSC projects in operation or under construction.

Figure 6 shows the accumulated effect of HVDC-VSC systems in operation or under construction.

Fast and reliable ICTs are equally important to power electronics to achieve a smart and strong T&D system. While FACTS and HVDC provide a flexible infrastructure, they require supervision and need to be constantly controlled. The fact that the system needs to be supervised and controlled is not new, but today there is much more information delivered in real time from multiple users in a wide area. This amount of information cannot be managed manually, but has to be automated. A key breakthrough was the implementation of IEC 61850 for Power Utility Automation, which allowed fast communication for different data for different applications. First developed in 2004, this standard is now implemented by all major manufacturers of devices and systems for protection and control of the power system, including for PMU and wide-area monitoring. In addition, the Common Information Model (CIM) standard is being adopted for IEC.

IEC 618580

The IEC Technical Committee 57, "POWER SYSTEMS management and associated information exchange," is covering important parts of the international standardization work for smart grids, as described in its strategic business plan:

- Provide smart grid interoperability standards for power system management and operation.
- Propagate and promote IEC 61850 as the Smart Grid core communication standard for power system automation of field devices and systems, both within and outside of substations (e.g., for distribution automation, distributed energy resources, monitoring & control in hydroelectric power plants, and wind turbines).
- Propagate and promote the use of IEC 61968 and 61970 CIM standards for enterprise-level Smart Grid functions both within an individual utility enterprise as well as between utilities, transmission system operators (TSOs), and regional transmission operators (RTOs).

IEC 61850 is primarily a global international standard for substation automation. Much more than just an open communication protocol, IEC 61850 also covers engineering, maintenance, and test procedures. In addition, IEC 61850 models substation equipment and protection and control functions, enabling self-description of connected devices and exchange of information between engineering tools. IEC 61850 9-2 standardizes the process by allowing integration of non-conventional instrument transformers (NCIT)—e.g., optical instrument transformers in a fully digital substation. Over time, the standard's principles and internal modelling have been expanded and applied to various fields—e.g., IEC 61850 adaptations for distributed energy resources (DER) (IEC 61850-7-420), hydropower (IEC 61850-7-410), and wind turbines (IEC 61400-25), and to transmit synchrophasor information per IEEE C37.118 (IEC 61850-90-5). IEC 61850 has also been used for communication between substations (IEC 61850-90-1). Development of IEC 61850 is continuing and expanding beyond the substation, as described in the new scope of the standard series second edition *IEC 61850 Communication Networks and Systems for Power Utility Automation*.

Further extensions are in progress, including the following: IEC 61850-90-2—Use of IEC 61850 for the communication between control centres and substations; IEC 61850-90-3—Using IEC 61850 for Condition Monitoring; and IEC 61850-90-4—Network Engineering Guidelines. IEC 61850 is already globally accepted and implemented, but there are still concerns to be handled. This is addressed within IEC, as well as by organizations such ENTSO-E and GO15.

IEC 61850 is a model for the design of ICT systems, and now covers many applications beside substation automation. It provides interoperability between different vendors and is "future-proof" for technology upgrades. Virtually all new substations in countries like China, India, South Africa, and Brazil are built with this standard. From 2004 to 2014, between 250,000 and 500,000 IEDs were deployed. Since the commercial introduction of IEC 61850 standard in 2004–2005, more than 40 manufacturers around the world

[1] Wind turbines (IEC 61400-25), hydro power (61850-7-410), DER, (IEC 61850-7-420), IEC 61850-90-1 — Use of IEC 61850 for the communication between substations, IEC 61850-90-5 — Use of IEC 61850 to transmit synchrophasor information per IEEE C37.118

have certified more than 400 types of IEDs at DNV-KEMA. The progress is slower in Europe and especially in the United States, because most applications are retrofits of old installations. This adds further requirements for interoperability, which has been addressed by ENSTO-E and GO15.

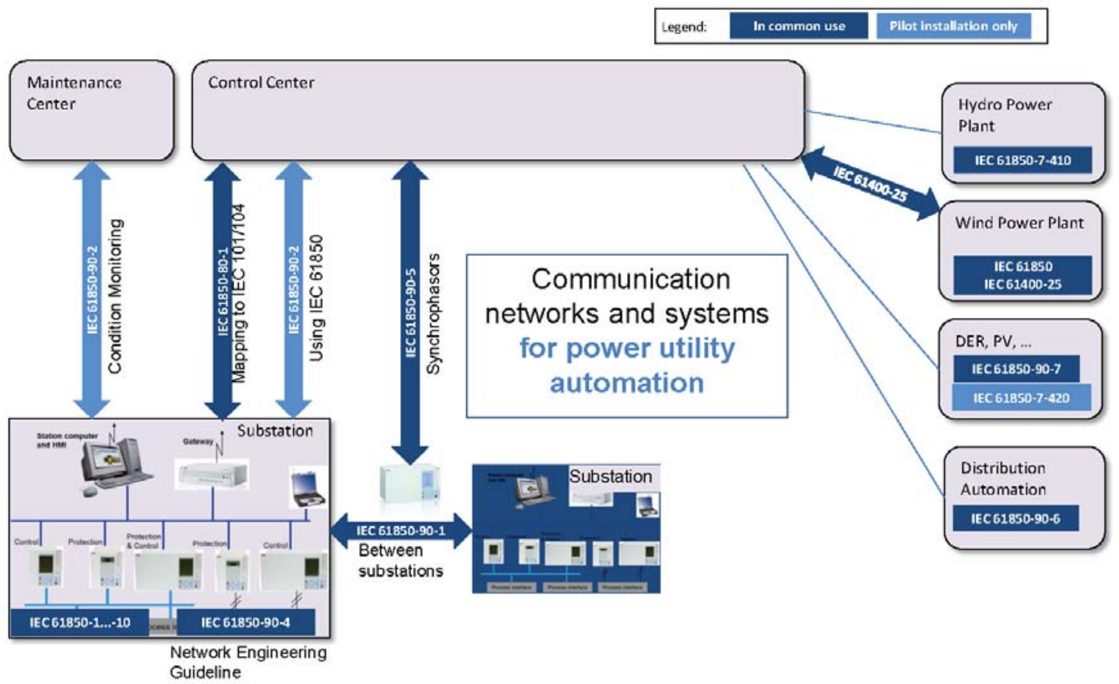


Figure 7: Interoperability standardization.

The level of interoperability needed in the digital power system will require ongoing development and implementation of standards by dedicated organizations, such as IEC, CENELEC, and the U.S. National Institute of Standards and Technology (NIST). Such standards should allow the interchange of data while also ensuring cyber security. This will demand cooperation among different stakeholders, and include planning and work-force empowerment through training and testing. Traditional skills in power engineering will need to be enhanced with new skills in ICT engineering. The implementation of new technology will drive the change and affect the sector's work force. Change management will be an essential part of the successful implementation of the digital power system in order to prepare the work force with necessary training.

Phasor Measurement Units

The traditional functions—monitor, protect, and control the power system—are well known and implemented in modern SCADA and Substation Automation Systems. However, recent disturbances have shown the need to add new functionality to monitor, protect, and control the complete interconnected power system. The basic building block of a WAMS is the PMU, which, through global positioning system (GPS) timestamping enables accurate voltage and current measurements at any location in the power system. Time synchronization makes it possible to measure voltages and currents as phasors that refer to the same system-wide angle reference. The PMU is therefore a measurement transducer, where the outputs are commonly referred to as "synchrophasors." The phasor measurements are streamed from their various locations (using different communication solutions) to phasor data concentrators, where the data is collected, processed, or stored for further applications.

Based on system-wide information from PMUs, it is now possible to monitor and observe the state of the power system in a way that was not possible with the conventional SCADA information systems based on remote terminal units (RTUs). WAMS have been under development in different places and at different paces during the last 20 years. WAMS are starting to mature as solutions, suitable for integration in control centre environments. Vendors of control centre systems also offer solutions with software that includes integration of synchrophasor data. The applications can execute functions that range from simple storing and display of phasor data to advanced post-processing of information and use in protection and control systems. Depending on the nature and use of these applications, they are referred to as WAMS, WAPS (wide-area protection systems), WACS (wide-area control systems), or WAMPACs, which includes all those classifications and can be used to control FACTS and HVDC. PMU deployment is most advanced in the United States and China, with several thousand installed. In other parts of the world, including Europe, deployment is slower, but many pilot projects are in different stages, including closed loop control of FACTS devices.

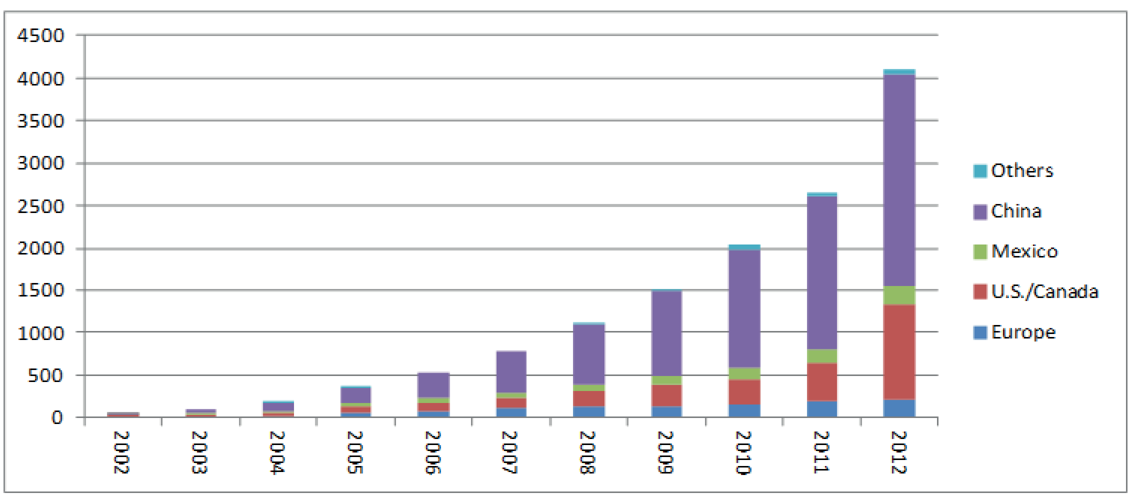
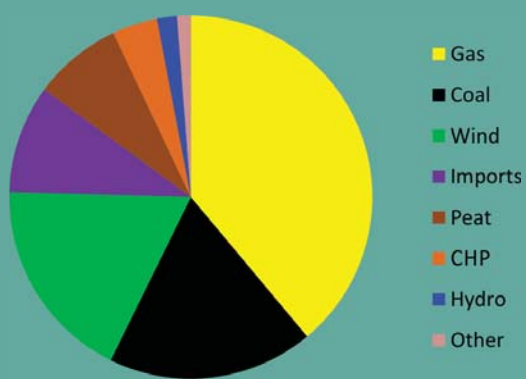


Figure 8: Total installed number of PMUs.

IRELAND

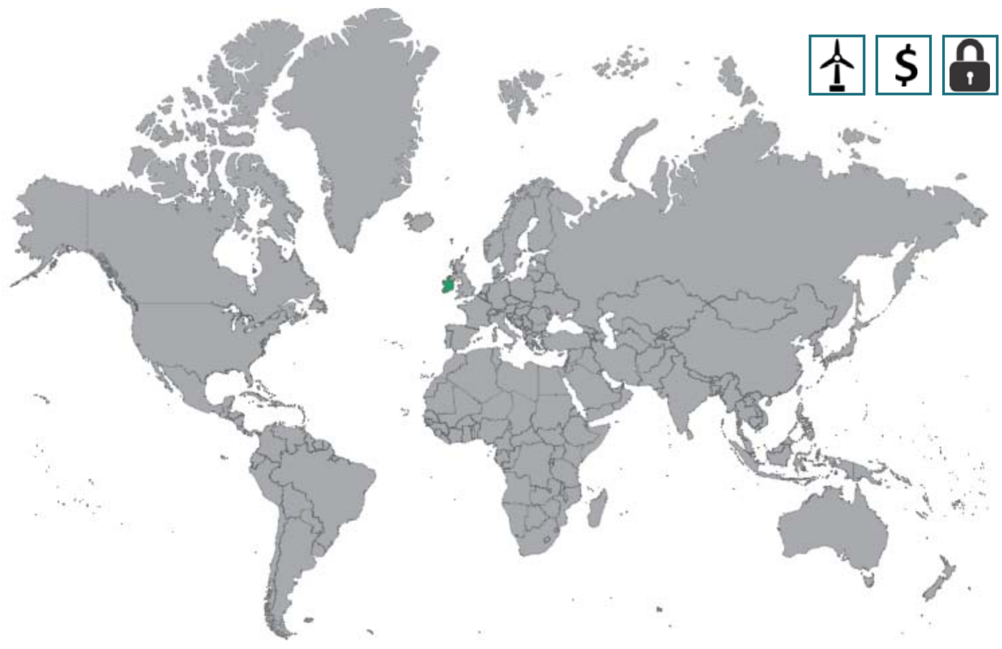
High-voltage direct current interconnector enables integration of wind power and improves electricity market

Photo: ABB

IRELAND	
Market Structure	One transmission and one distribution company (both regulated); all-island (Ireland and Northern Ireland); single electricity market; retail fully deregulated.
Electricity Consumed (2014)	26,815 GWh (All-Island 35,587 GWh)
Peak Demand (2014)	4,771 MW (All-Island 6,466)
System Type	Ireland and Northern Ireland form a synchronous power system
Electricity Fuel Mix	
Installed Power (2014)	Conventional: 7,270 MW (All-Island 9,901MW); Wind: 2,211 MW (All-Island 2,825 MW)
Interconnection	There are two HVDC links between the island of Ireland and Great Britain: the Moyle Interconnector (current operational capacity of 250 MW) links Northern Ireland to Scotland; and the East-West Interconnector (500 MW capacity) links Ireland to Wales.
Contact	Séamus Power EirGrid plc seamus.power@eirgrid.com

IRELAND

High-voltage direct current interconnector enables integration of wind power and improves electricity market



CASE

Project name:	**East-West Interconnector**
Leading organization:	**EirGrid**
Commissioning year:	**2012**
Type of project:	**Commercial**

CASE HIGHLIGHTS

Key enabler of Ireland's 2020 target of 40% electricity from renewable sources

Exerting downward pressure (9%) on the Single Electricity Market

Advanced Ancillary Services to the Irish and Great British transmission systems, including:

- Fast Frequency Response; Black start capability; and Reactive Power and Voltage Control.

Community Involvement

- During construction, communicated and interacted via dedicated community liaison officers, local information office, leaflet drops, website updates, social media, text messaging, targeted informative leaflets and advertisements in local papers.
- Engaged with local schools to promote engineering as a career using the EWIC project as a model to inform students about the challenges and satisfactions of engineering as a career choice.

Improved Security of Supply

Introduction

The East-West Interconnector (EWIC), the largest voltage source converter high-voltage direct current (HVDC-VSC) scheme in operation when commissioned in 2012, links the electricity transmission grids of Ireland and Great Britain by connecting convertor stations at Woodland in Ireland to Shotton in Wales. Totalling 264 km in length, 187 km of which is beneath the Irish Sea (see Figure 9), this project represents a significant investment that holds considerable benefits for Ireland by improving the security of supply, increasing competition in the market, and helping the country reach its renewable electricity targets.

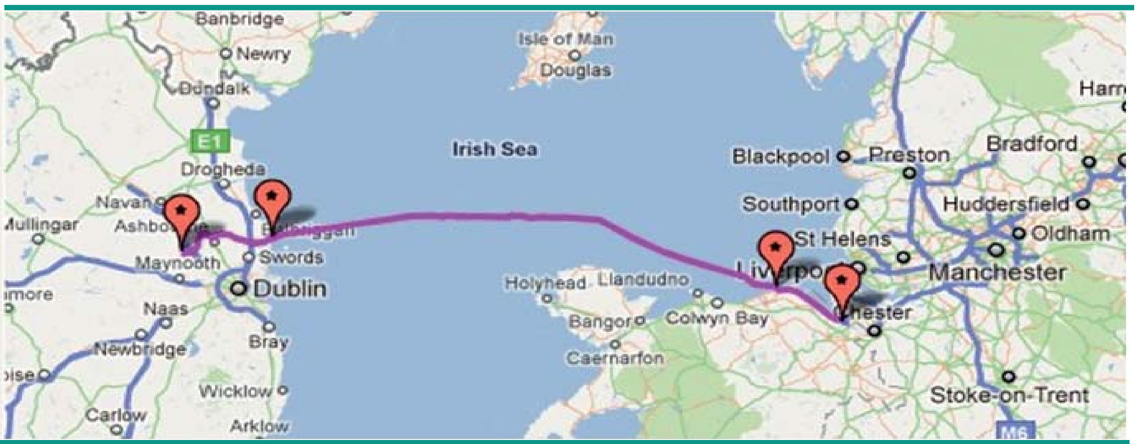


Figure 9: Map depicting the East-West Interconnector.

Studies for an Ireland-Great Britain interconnection date back to the 1970s, when the Irish Electricity Supply Board first examined the possibility of linking the electricity grids. Further studies were conducted in the early 1990s, including a joint study conducted by the Electricity Supply Board and National Grid UK with the support of the European Union.

In 2006, the Irish Minister for Communications, Energy, and Natural Resources deemed a regulated 500 MW interconnector to be critical infrastructure, and instructed the Commission for Energy Regulation (CER)—the Irish energy regulator—to commence development. In January 2007, CER commissioned EirGrid—the transmission system operator in Ireland—to construct the interconnector linking Great Britain's and Ireland's electricity markets, with a completion date of the end of 2012. This was the tightest timescale that had ever been set for an interconnector of this scale.

EirGrid commenced work on EWIC in 2007, and it went into commercial operation in December 2012. The completion of EWIC produced an interconnection between Ireland and Great Britain with a capacity of 500 MW, equivalent to approximately 10% of Ireland's peak electricity demand. This is a significant addition to the Irish power system and fulfils the non-binding EU target for member states to achieve 10% electricity grid interconnection. EWIC also provides a range of ancillary services, such as fast frequency response, reactive power provision and has the capability to "black start" the electrical transmission systems of either Ireland or Great Britain in the event of a major system-wide outage.

Completion of the project from the placing of contracts to commercial operation took 45 months and involved 285 contractors. The work force exceeded 3,700 people at its peak, with an approximate total of 2.2 million hours worked. The original budget for EWIC was €601m; however, the final project cost came in significantly under budget at €570m.

Objectives and Benefits

EWIC had three key objectives:

- Improve the position of the island of Ireland with regards to the security of supply by providing additional capacity.
- Exert downward pressure on wholesale electricity prices in Ireland by providing direct access to Great Britain's larger electricity market and therefore enhance competition in the Irish market—importing cheaper power from Great Britain reduces the need for more costly and less fuel efficient power generation in Ireland.
- Allow the export of excess power from Ireland at times of oversupply to the Irish network. As an island on the periphery of Europe with a relatively small energy market, Ireland depends on price-volatile imported fossil fuels. However, Ireland is also rich in renewable energy resources. The Irish government has set an ambitious target of generating 40% of electricity from renewable energy sources (RES) by 2020. EWIC is a key enabler for achieving this target: when generation from wind, hydropower, and other renewable sources outstrips demand for electricity in Ireland, the surplus generation can be exported to Great Britain via the interconnector. As a result, growth of indigenous renewable energy is promoted and dependence on imported fossil fuels is reduced, causing a subsequent decrease in the economic price risk associated with reliance on these fossil fuels. Increased renewable energy generation will also reduce carbon emissions.

Technology

The EWIC project posed a significant challenge in providing an asynchronous high-power interconnector between the electrical grids in Ireland and the United Kingdom, which have very different characteristics. This challenge was solved by the application of the latest generation of high-voltage direct current (HVDC) technology provided by ABB: HVDC Light.

For the transmission distance (in excess of 260 km), HVDC represented the optimum whole-life techno-economic solution, principally because of its low power losses. It also provided a solution that has minimal environmental impacts. The project used the latest variant of HVDC-VSC technology. Requiring only minimal maintenance, the advanced power electronic equipment, together with its digital control and protection system, provides a highly reliable interconnection over a lifetime of 40 years. All aspects of the scheme's design and construction considered this requirement for longevity. The complete scheme was designed to ensure compliance with the International Organization for Standardization (ISO) procedures of ISO 9001 (Quality), ISO 14001 (Environmental), and ISO 18001 (Occupational Health and Safety).

The scheme uses extruded plastic insulation (cross-linked polyethylene [XLPE]) for the power transmission cables and, at ±200 kV direct current (DC), represented at the time of commissioning the highest DC voltage at which such cables had been used. It was a major advance for XLPE cable technology, demonstrating its suitability for long-distance HVDC submarine and underground cable schemes. As there is no oil used in the cable manufacture, XLPE represents a much more environmentally friendly solution than conventional oil/paper insulated cables.

A key feature of the new VSC technology is its compact design, which requires approximately half of the space of older HVDC technology. The scheme uses an advanced digital control system to optimize performance during normal operation, including minimizing operating power losses, whilst automatically changing to a dynamic operating mode to provide rapid response during system perturbations. Thus, in addition to its primary role of importing and exporting power, the scheme also provides ancillary services to Ireland and Great Britain's transmission networks, including reactive power and voltage control, and fast frequency response in the event of system faults, and system reserves to both national grids. A key feature of this scheme is its ability to "black start" either of the interconnected alternating current (AC) transmission grids. In the event of a major blackout in Ireland or Great Britain, the interconnector can be used to provide power to the blacked out system, speeding up the restoration of the grid.

To provide dedicated communication between the two converter stations, a fibre optic cable is laid with the power cables. The capacity on this cable can also facilitate commercial data transmission. Cutting-edge distributed strain and temperature sensing (DSTS) technology also operates on the fibre optic cable, providing diagnostic information on power cable condition. This information is displayed via the bespoke server-based geographical information system (GIS) monitoring facility, capturing real-time and historic cable data trends and monitoring shipping activity. This allows for early identification and location of faults and automatically alerts EirGrid about vessels anchored near the cables.

IRELAND

High-voltage direct current interconnector enables integration of wind power and improves electricity market

Technical data:	
Commissioning Year:	2012
Power Rating:	500 MW in both directions
No. of Circuits:	1
AC Voltage:	400 kV
DC Voltage:	±200 kV
Length of DC Underground Cable:	2 x 75 km
Length of DC Submarine Cable:	2 x 186 km
Main Reasons for Choosing HVDC Light:	Length of land and sea cables, controllability, "black start" capability, and active and reactive power support
Application:	Interconnecting grids

Community Engagement

The construction of the convertor stations and associated cables required engagement with local communities impacted by these developments. The use of ducts for the cable installation was chosen to minimize the disruption in public road use. Detailed traffic management plans were put in place to minimize disruption to businesses and landowners along the route. Local businesses and households were kept informed of the installation works via discussion, leaflet drops, updates using the EirGrid website, social media, text messaging, informational leaflets produced specifically for impacted businesses, and advertisements in local newspapers.

EirGrid funded two full-time community liaison officers to work with local councils to facilitate coordinated communications and interactions with the council executive, local councillors, and the wider public. In addition, EirGrid opened a local information office where members of the project team worked and met with members of the public and were available to answer queries as they arose. At specific locations, EirGrid funded the installation of footpaths to improve pedestrian safety and resurfaced roads to improve the safety and quality of roads for local vehicles. With the assistance of Engineers Ireland, EirGrid actively engaged with primary schools along the route to promote engineering as a career, using the EWIC project as a model to inform students about the challenges and satisfactions of engineering as a career choice. This proved very successful and was repeated at all schools at their request over a three-year period.

EirGrid committed financially to local projects in the communities directly affected by the works, distributing funds to local authorities and initiatives that benefited the local communities (e.g., local community centres, sporting clubs, and sporting competitions).

Current Status and Results

Analysis completed in 2014 after one year of full commercial operation demonstrated that the load-weighted average system marginal price (SMP) in the Single Electricity Market (SEM – wholesale electricity market of Ireland and Northern Ireland) was reduced by 9% compared to if EWIC was not present. It is clear that EWIC is facilitating competition and in doing so is exerting downward pressure on wholesale electricity prices as a result of increased power imports. This increased competition is narrowing the gap in the cost of electricity between the islands of Ireland and Great Britain, facilitated by generators located elsewhere in the European Union, particularly in Great Britain.

A number of market participants from across Europe now trade energy on EWIC between the All-Island SEM and the British Electricity Trading Transmission Arrangements (BETTA). EWIC customers actively compete for long-term (annual, seasonal, quarterly, and monthly) and daily auction products. Flows on the interconnector to-date have been predominantly from Great Britain to Ireland.

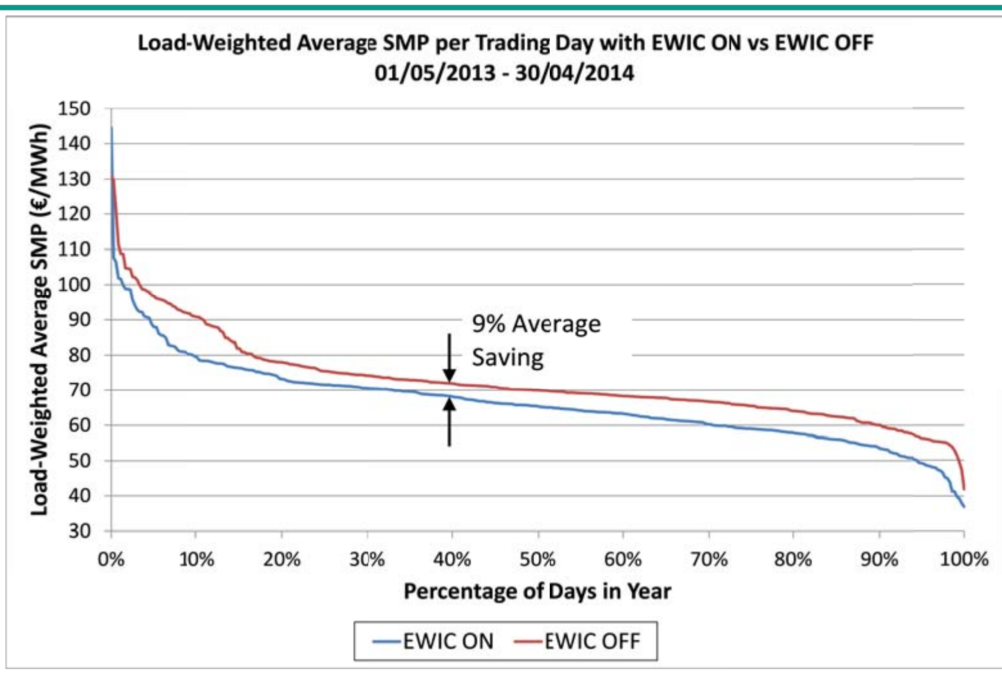


Figure 10. Auction price per capacity product by date of auction.

Approximately €3 million per month in auction revenue is collected from market participants seeking to acquire capacity; this revenue directly increases the value of the interconnector to the Irish consumer. The number of customers across Europe registering to trade on EWIC is increasing, and, in terms of the development of the European internal energy market over the coming years, it is likely that further market participants will begin to trade. This increased participation will be good for competition and will provide additional benefits to electricity consumers.

In addition, EWIC is facilitating the development of the indigenous renewable energy market and provides export potential to help Ireland achieve its European 2020 40% renewable energy target. This reduces Ireland's carbon footprint and helps ensure that benefits of the EWIC will be enjoyed for many generations in the future. To this end, EirGrid has been working hard to reduce RES curtailment through the use of system operator trades directly with National Grid UK and with its trading partner Statkraft, recording priority dispatch trade volumes of 300 GWh and associated reduction in dispatch balancing costs of €8.4 million in the six-month period between July and December 2013.

Lessons Learned and Best Practices

The choice of technology used to connect the power systems of Ireland and Great Britain was key to the success of EWIC in terms of the benefits to the Irish consumer. The latest variant of HVDC-VSC technology represented the optimum whole-life techno-economic solution; it is well-suited to the particular technical characteristics of island systems and provides ancillary services to both Ireland's and Great Britain's transmission networks, including "black start" capability.

Developing and maintaining good relationships with the many and varied stakeholders was key to the success of the EWIC project. The project cultivated good relationships with local councils and regularly sought their advice, which subsequently led to very few problems being encountered. Full-time community liaison officers and a local information office kept local communities and businesses informed at every stage of the process. Also, efforts to commit financially to community projects proved very successful.

Consents were managed separately in each jurisdiction, and there were separate project managers for Ireland, Great Britain, and the marine works. The clear split in roles worked well and ensured focus on the overall completion of the project. The complete scheme was designed to ensure compliance with the procedures of ISO 9001 (Quality), ISO 14001 (Environmental), and ISO 18001 (Occupational Health and Safety).

Next Steps

Following the success of the EWIC project, further future interconnection between the island of Ireland and the wider European power system is being considered. In June 2013, EirGrid and its French counterpart, RTE, signed a Memorandum of Understanding to commission further preliminary studies on the feasibility of building a submarine electricity interconnector between Ireland and France. An Ireland-France interconnector would run between the south coast of Ireland and the northwest coast of France and would comprise a cable length of approximately 600 km. Over recent months, EirGrid and RTE conducted studies that indicated an interconnector between the two countries could be beneficial for electricity customers in both Ireland and France. Subsequent studies will focus on desktop analysis of the seabed to identify potential route corridors.

IRELAND

High-voltage direct current interconnector enables integration of wind power and improves electricity market

SUMMARY: EAST-WEST INTERCONNECTOR

What is the project about?

The East-West Interconnector (EWIC) is a voltage source conversion high-voltage direct current (HVDC-VSC) link connecting the electricity transmission grids of Ireland and Great Britain. It is 264 km long, 187 km of which is beneath the Irish Sea, and has a capacity of 500 MW (equivalent to approximately 10% of Ireland's peak electricity demand). EWIC also provides a range of ancillary services, such as frequency response and reactive power provision, and includes the capability to "black start" the electrical transmission systems of either Ireland or Great Britain in the event of a major system-wide outage.

Main goals

The EWIC project had three key objectives:

- Improve the security of supply by providing additional capacity.
- Exert downward pressure on wholesale electricity prices in Ireland by providing direct access to Great Britain's larger electricity market.
- Allow the export of excess power from Ireland at times of oversupply to the Irish network.

Current status/timeline

EirGrid commenced work on EWIC in 2007, and it went into commercial operation in December 2012.

What is the result/expected benefits of the project?

Analysis completed in 2014 after one year of full commercial operation demonstrated that the load-weighted average system marginal price (SMP) in the Single Electricity Market of Ireland and Northern Ireland was reduced by 9% compared to if EWIC was not present. Increased competition and pressure is narrowing the gap in the cost of electricity between the islands of Ireland and Great Britain, facilitated by generators located elsewhere in the EU, particularly in Great Britain.

EWIC is also facilitating the development of the indigenous renewable energy market and provides export potential to help Ireland achieve its European 2020 40% renewable energy target. EirGrid has been reducing RES curtailment through the use of EWIC system operator trades recording priority dispatch trade volumes of 300 GWh in the six-month period between July and December 2013.

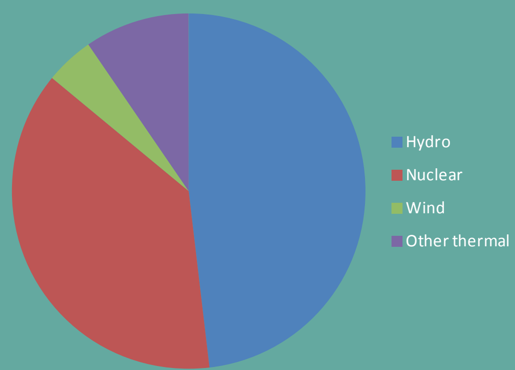
What is next?

Following the success of the EWIC project, further future interconnection between the island of Ireland and the wider European power system is being considered.

SWEDEN

Optimal combination of transmission technologies solves transmission congestion

Photo: Stockphoto

SWEDEN	
Market Structure	Sweden is part of the fully integrated, deregulated Nordic power market and is synchronously connected to Norway, Finland, and Denmark East. The market includes one transmission company and approximately 170 regional and local grid companies.
Electricity Consumed (2012)	142,400 GWh
Peak Demand (2012)	26,760 MW
System Type	The system is characterized by total integration of the electricity market and strong physical integration. Interconnection capacity between the countries is typically around 30% of peak power.
Electricity Fuel Mix	
Installed Power	38,300 MW[1]
Interconnection	Sweden has six HVDC interconnections to the neighbouring countries—Finland (2), Denmark (2), Poland (1), and Germany (1)—with a total capacity of 3,200 MW. One HVDC to Lithuania is under construction and will be operational in 2016, and another one to Germany is planned.
Contact	Ulf Moberg Svenska Kraftnät ulf.moberg@svk.se

[1] Due to reduced production capacity during the winter period, Svenska kraftnät estimates the available production capacity during peak demand to be 27,500 MW.

SWEDEN

Optimal combination of transmission technologies solves transmission congestion

CASE

Project name:	**South West Link**
Leading organization:	**Svenska kraftnät**
Commissioning year:	**2015**
Type of project:	**Commercial**

CASE HIGHLIGHTS

Optimal choice of transmission technologies

- Combination of overhead AC and DC; underground DC.
- No new right-of-way required.
- Increased transmission capacity for the overhead linewithin existing right-of-way.
- 200 km, 1200 MW underground line for virgin land.
- HVDC-VSC technology suited for future expansion to HVDC grid.

Ancillary service

- Increased transmission capacity and voltage collapse avoidance in existing grid by reactive power control.

Introduction

The South West Link is a combined alternating current (AC) and voltage source converter high-voltage direct current (HVDC-VSC) transmission line totalling 427 km in length, which reinforces the transmission grid between mid- and southern Sweden. The northern part of the link is a 176 km 400 kV AC overhead line (OHL) between the substations Hallsberg and Barkeryd. The southern part is a 251 km direct current (DC) transmission line between the substations Barkeryd and Hurva, which is divided into two parts: 61 km OHL and 190 km underground cable (see figure 11).

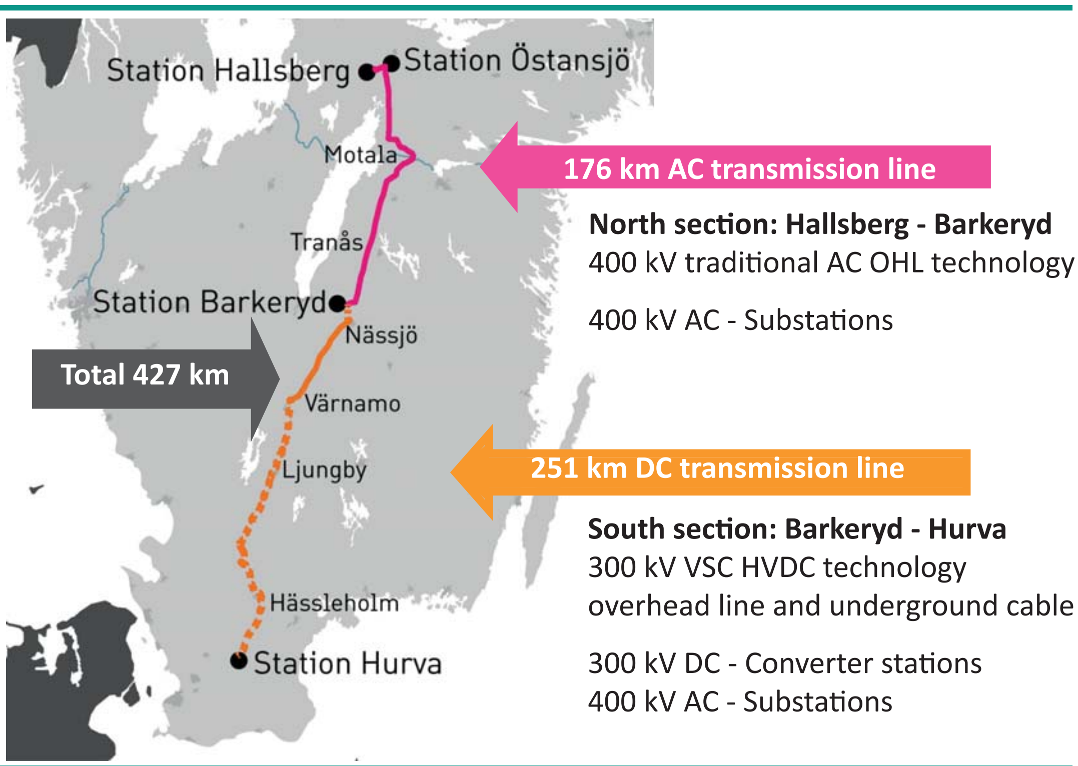


Figure 11: The South West Link.

This project is the largest and single most important project ever for Svenska kraftnät (Swedish national grid), and represents a significant investment. The project has many drivers and will yield considerable benefits to Sweden, especially the southern parts. From the beginning, the main drivers included increasing the reliability and improving the security of supply to the south of Sweden after a 2003 blackout in this part of the country and Zealand in Denmark. Increasing the transmission capacity to southern Sweden has also become a main driver, especially after the decommissioning of the nuclear power plant in Barsebäck (located on the coast west of Hurva), which led to increased capacity limitations in the region due to voltage instability problems. The South West Link is also an important part of the necessary development of the national grid, which is required to enable the introduction of renewable energy in accordance with Swedish and EU energy policy objectives.

SWEDEN

Optimal combination of transmission technologies solves transmission congestion

The analysis that followed the 2003 blackout in the south of Sweden demonstrated the need for the construction of a new transmission line between mid- and southern Sweden to increase the reliability and robustness of the grid. The analysis focused on discovering which technology should be used and the optimal route for the transmission line. The initial idea was to construct a new 400 kV AC OHL using the route of an existing, old (more than 70 years old), 220 kV OHL. In parallel, possible underground cable routes were also investigated. It was ultimately determined that an OHL alternative would significantly delay the project, as it would not be possible to obtain permission for an OHL alternative for the whole route within a reasonable time.

Parallel studies initiated within Nordel—the organization for all the Nordic transmission system operators (TSOs)—showed a need to increase capacity on the Swedish west coast and between the southern part of Norway and Sweden. These needs extended the project to also include an HVDC-VSC transmission line between Barkeryd and the Oslo area, converting the project to a multi-terminal interconnection between Sweden and Norway. This western part from Sweden to Norway was, however, later terminated (2013).

The final system design (south and west) was presented in 2008. Because this part of Sweden is relatively densely populated, and to maximise the capacity to fully utilize the right-of-way, the conclusion was to design an HVDC-VSC solution with as high a capacity as possible. At this time, the manufacturers stated that cable was the only option for the HVDC-VSC technology. That assessment was later changed: one part of the line was revised to OHL HVDC-VSC. For the OHL part, both AC and DC, the right-of-way from an old 220 kV line was used to minimize the impact of land use.

Commissioning is planned for 2015, and will increase the capacity in the congested intersection in the southern part of the transmission grid by approximately 25%.

This interconnection will represent a transmission system presently without comparison in the world, featuring the following attributes:

- One of the world's largest HVDC-VSC systems.
- Complete hybrid solutions with all major transmission technologies: OHL AC, OHL DC, and underground DC in the same project.
- The world's largest underground system with respect to distance and capacity (190 km and 1,200 MW).
- Embedded HVDC system in contrast to the normal HVDC application with inter-connection between systems.
- Unique concentration of large HVDC-VSC terminals with potential to create system services such as active and reactive voltage support.

Objectives and Benefits

The South West Link has four key objectives:

- Improve the reliability of the transmission grid in the southern part of Sweden, preventing large disturbances like the 2003 blackout.
- Enhance the security of supply to the southern part of Sweden after the decommissioning of the Barsebäck nuclear power plant located far south in Sweden.
- Increase the transfer capacity to the south of Sweden to reduce the price differences between bidding areas in Sweden and also increase possibilities to export power from Sweden.
- Enable the ability to connect and transfer power from renewable energy sources.

Many stakeholders will benefit from the South West Link, including producers that will enjoy increased possibilities to export power, consumers in the south part of Sweden that will see a lower electricity price, and traders that will have reduced risks for their positions in the southern part of Sweden.

After a ruling from the EU saying that Svenska kraftnät was not allowed to limit exports because of internal grid congestions, Sweden was divided into four bidding areas in 2011 (see figure 12). The consequence of this for the electricity market is a risk for differentiated electricity prices in Sweden in case of grid congestions. The main risk identified was for the southern part of Sweden, where the Barsebäck nuclear power plant had been decommissioned, resulting in increasing limitations of the export possibilities.

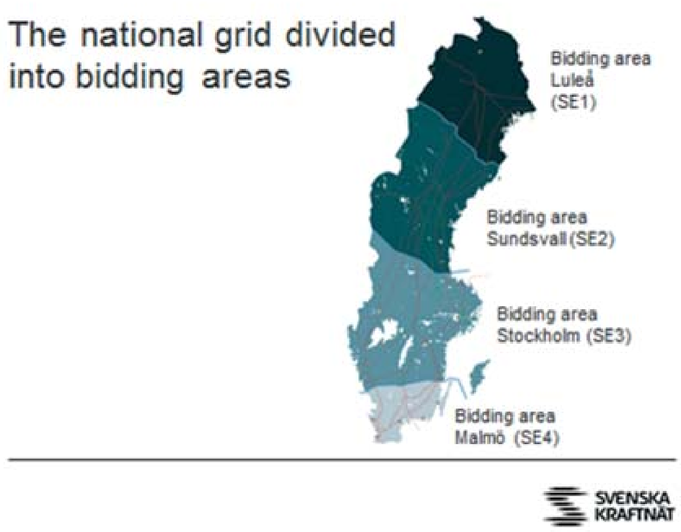


Figure 12: The bidding areas in the Swedish power system.

So far, the only noticeable price difference between the bidding areas has, as expected, been between bidding areas SE3 and SE4 (see Figure 13). Hence, this is the background for one of the main objectives of the South West Link.

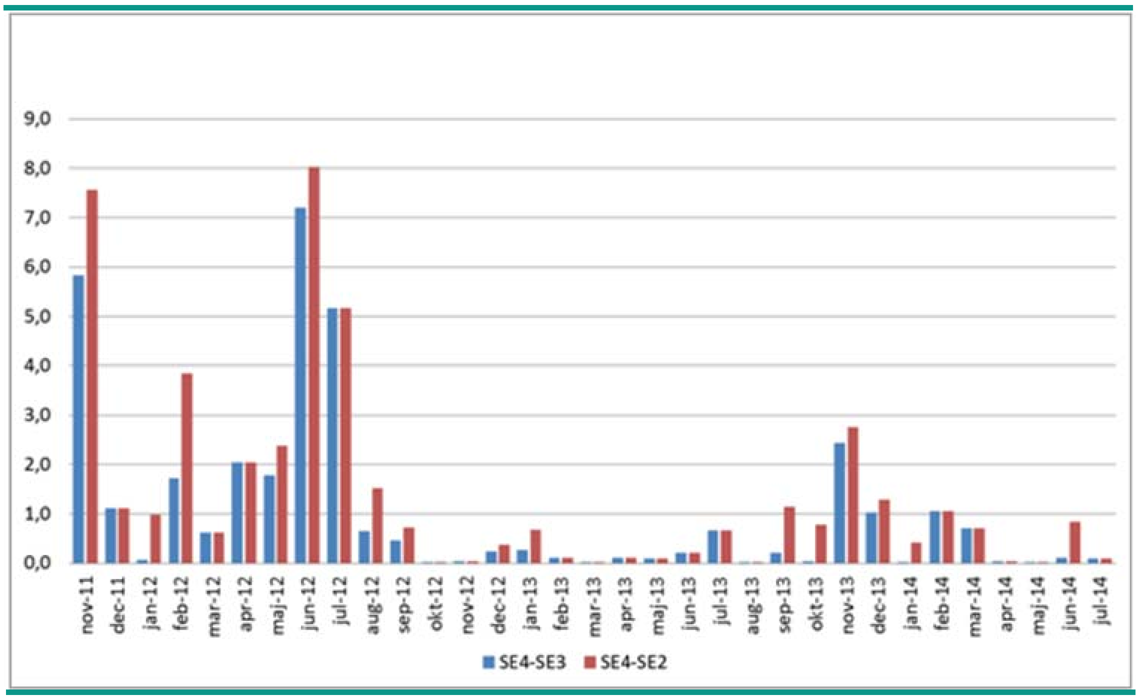


Figure 13: Price difference between bidding areas.

Figure 13 shows the price difference between bidding area SE4 and SE3 (blue) and between SE4 and SE2 (red) from the introduction of the four bidding areas in 2011. As can be seen, there were some large price differences during the first 9 months. This was caused by problems in nuclear power plants reducing the grid capacity in the south of Sweden. In the last two years, the price differences have been considerably smaller.

Technology

As mentioned in the introduction, the South West Link is a combined AC and HVDC-VSC transmission line. The northern part of the link is an AC OHL and the southern part is a DC transmission line, divided into one OHL part and one underground cable part. Different cable installation methods were used depending on the type of soil conditions. Ducts were used to minimize the disruption in public road use and environmental impact where needed (e.g., under roads, lakes, and other sensitive areas).

Utilization of the route of the existing 220 kV OHL from Hallsberg down to Värnamo (see map in Figure 11) made an AC and DC OHL solution possible and less controversial than a new route would have been. In this area the main need was to strengthen the electricity grid, creating a stronger and more meshed grid with low need for controllability from an HVDC installation. Keeping costs as low as possible was also a goal for the project, which favoured the AC solution.

AC technology was chosen for the northern part of the South West Link to ensure flexibility for future changes in the grid, such as connections to new power plants (e.g., wind power), new lines, and new or increased consumption.

HVDC-VSC was chosen for the southern part of the South West Link to maximize the controllability and capacity in the corridor. HVDC-VSC increases controllability through the potential to support and control the voltage in southern Sweden and also the possibility to control (in principle) the reactive power (generation and consumption) independent of active power increase, which was a very important feature because the risk of a voltage collapse is limiting the capacity in this part of the grid.

In addition, HVDC allows a greater increase in transmission capacity between Barkeryd and Hurva (see map in Figure 11) than what could be achieved with 400 kV AC. It is very difficult to get permission for transmission line corridors in this part of Sweden because there are many conflicting interests, and the forecasts for the Swedish energy balance also predicted that there was a high probability for a future energy surplus, leading to increased demand for export capacity.

The South West Link will be the first embedded HVDC link in the Swedish transmission grid, resulting in new operational challenges and opportunities.

Technical data:	
Commissioning Year:	2015
Power Rating:	2 x 600 MW in both directions
No. of Circuits:	2
AC Voltage:	400 kV
DC Voltage:	±300 kV
Length of AC Overhead Line:	176 km
Length of DC Overhead Line:	61 km
Length of DC Underground Cable:	2 x 190 km
Main Reasons for Choosing HVDC-VSC:	Controllability, reactive power support, transfer capacity, and multi-terminal potential

Community Engagement

The construction of the OHL and cables required engagement with local communities. Communities and land owners were kept informed about the development through meetings, the Svenska kraftnät website, and brochures with project news.

Although the AC OHL was constructed in the existing route from an old 220 kV line and one section that passed through the town of Motala (see map in Figure 11) was moved outside the town, the OHL project saw significant opposition and objections from different stakeholders. In response, Svenska kraftnät chose to reduce the environmental impact by raising a couple of design towers on a sensitive crossing. The cable route met less opposition, but in some areas the objections became quite strong for this part of the project. The DC stations and convertor buildings went through rigorous examination by the communities, which resulted in far-reaching requirements for the design.

Current Status and Results

The project consists of a number of sub-projects that are currently in different phases. The AC OHL, AC stations, and DC OHL and cable are in the finalizing phase, while the DC stations and convertors are in an earlier phase.

Lessons Learned and Best Practices

The South West Link project has taught Svenska kraftnät a number of lessons and provided the company with a number of good experiences. Projects like this require a lot of preliminary work to ensure that the project runs as smoothly as possible. It is also important to have a thorough procurement strategy and plan. In the case of the South West Link project, little work was conducted in advance. A lot of time elapsed between the blackout in 2003, the start of the analysis in 2004, and when the investment decision finally was made in the beginning of 2008 after long technology discussions and dialogues regarding the permission process. This delay resulted in high ambitions to start the project as quickly as possible, which led to shortcuts in analysis. As a result, questions that arose during the project had to be handled rather rapidly and with less accuracy than desirable.

One key factor to the project's success has been the extensive and intensive communication activities to inform land owners, communities, and other stakeholders about the project in an early stage.

Next Steps

The project is working hard to achieve results and ensure the connection will be operational in 2015. The AC stations are in operation, and the cable project is almost finished. Work is still ongoing on the OHL parts and the HVDC stations.

Less than a year after the South West Link is operational, a second large HVDC-VSC project will begin operation: the NordBalt Link—a 300 kV 700 MW interconnector between Sweden and Lithuania—will connect the Nordic power market with the emerging Baltic power market.

SWEDEN

Optimal combination of transmission technologies solves transmission congestion

SUMMARY

What is the project about?

The South West Link is a combined alternating current (AC) and voltage source converter high-voltage direct current (HVDC-VSC) link totalling 427 km in length, reinforcing the transmission grid between mid- and southern Sweden. The northern part of the link is a 176 km 400 kV AC overhead line (OHL) and the southern part is a 251 km DC transmission line divided into a 61 km OHL and a 190 km underground cable. Commissioning is planned in 2015, and will increase the capacity in the congested intersection in the southern part of the transmission grid by approximately 25%.

Main goals

The South West Link project has four key objectives:

- Improve the reliability of the transmission grid in the southern part of Sweden.
- Enhance the security of supply to the southern part of Sweden after the decommissioning of the Barsebäck nuclear power plant located far south in Sweden.
- Increase the transfer capacity to the south of Sweden to reduce the price differences between bidding areas in Sweden and also increasing the possibilities to export power.
- Enable the ability to connect and transfer power from renewable energy sources.

Current status/timeline

The project is working hard to achieve results and ensure the connection will begin operation in 2015. The AC stations are in operation, and the cable project is almost finished. Work is still ongoing on the OHL parts and the HVDC stations.

What is the result/expected benefits of the project?

The project has many drivers and will yield considerable benefits to Sweden, especially to the southern parts. From the beginning, the main drivers were to increase the reliability and improve the security of supply to the south of Sweden. Increasing the capacity to the south part of Sweden has also become a main driver, especially after the decommissioning of the nuclear power plant in Barsebäck (located at the coast west of Hurva), which led to increased capacity limitations in the south of Sweden due to voltage instability problems. The South West Link is also an important part in the necessary development of the national grid, which is required to enable the introduction of renewable energy planned in accordance with Swedish and EU energy policy objectives.

What is next?

Less than a year after the connection is made operational, a second large HVDC-VSC project will commence operation. The NordBalt link, a 300 kV 700 MW interconnector between Sweden and Lithuania, will link the Nordic power market with the emerging Baltic power market.

UNITED STATES

Wide-area measurement systems used to avoid large-scale outages

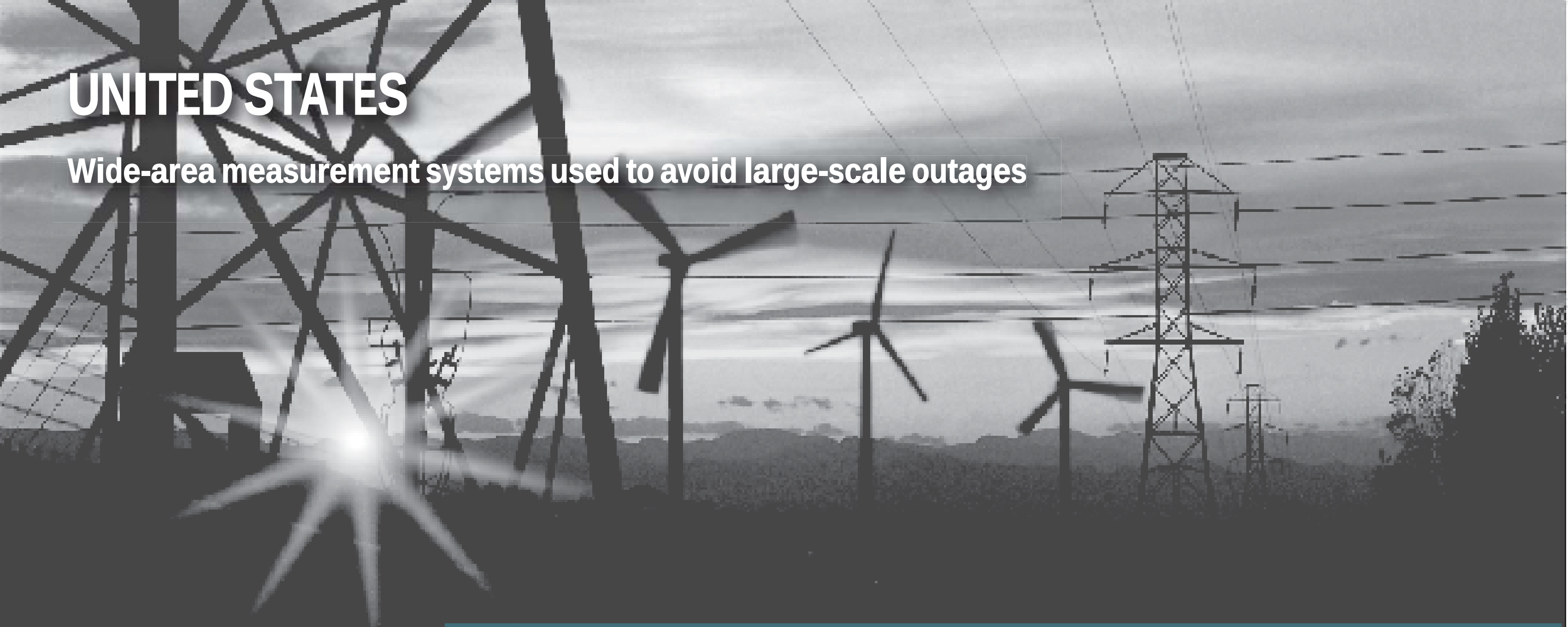


Photo: NREL

UNITED STATES	
Market Structure	In the United States, no standard model or combination of actors, mechanisms, or ownership typifies electricity generation and delivery.
Electricity Consumed (2012)	4,095,00 GWh
Peak Demand (2012)	767,762 MW
System Type	Three synchronous interconnections.
Electricity Fuel Mix (2013)	

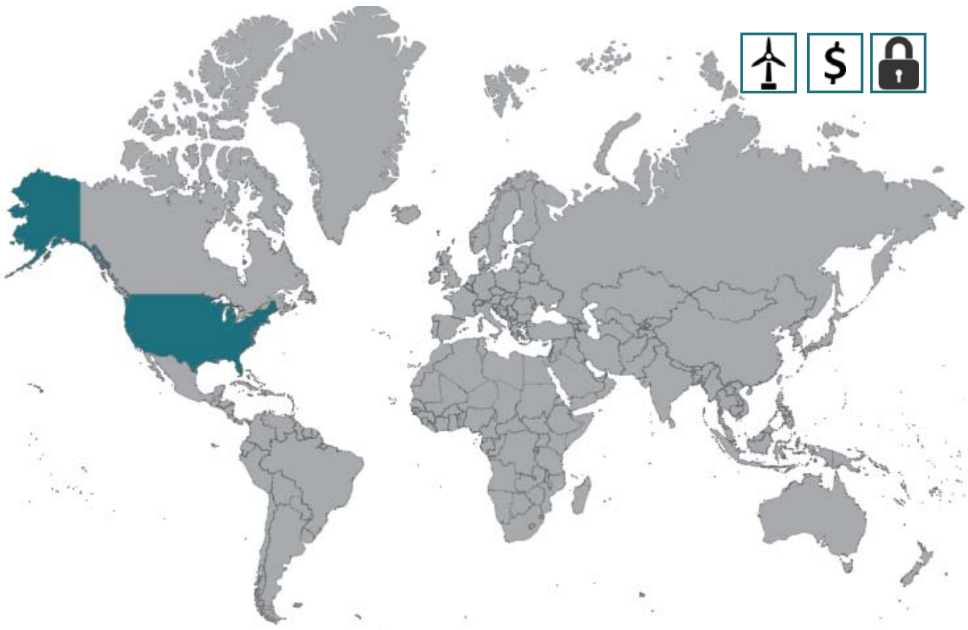
	Ratio
Coal	39%
Natural Gas	27%
Nuclear	19%
Hydro	7%
Wind	4.1%
Other RES	1.9%
Petroleum	1%

Installed Power	1,063,000 MW[1]
Interconnection	The United States T&D system comprises three interconnections: the Eastern and Western Interconnections cover most of eastern and western North America, respectively, and are tied together via high-voltage direct current links. The third interconnection is the Texas Interconnection, which covers most of Texas.
Number of PMUs	The Smart Grid Investment Grant (SGIG) program participants have deployed 1819 PMUs across the United States, of which 126 is installed by by the Bonneville Power Administration..
Contact	Philip N. Overholt U.S. Department of Energy Philip.overholt@hq.doe.gov

[1] Net summer generating capacity 2012. Source: U.S. Department of Energy's Energy Information Administration

UNITED STATES

Wide-area measurement systems used to avoid large-scale outages



CASE

Project name:	Western Interconnection Synchrophasor Program
Leading organization:	The Western Electricity Coordinating Council, Bonneville Power Administration
Completed installation:	2013
Type of project:	Deployment Grant

CASE HIGHLIGHTS

Increases potential power transmission without immediate build-out by leveraging real-time information and automated controls to detect and mitigate oscillations

Accounts for new sources of supply (i.e., renewable energy)

Avoids large-scale outages (conservative estimated value of $1.2B to $3.5B in avoided economic losses)

Introduction

The Western Electricity Coordinating Council (WECC) is one of eight electric reliability councils in North America, encompassing a geographic area equivalent to more than half of the United States. WECC members provide electricity in 14 western states, 2 Canadian provinces, and part of 1 Mexican state. WECC promotes electrical system reliability and provides a forum for coordinating the operating and planning activities of its member organizations.

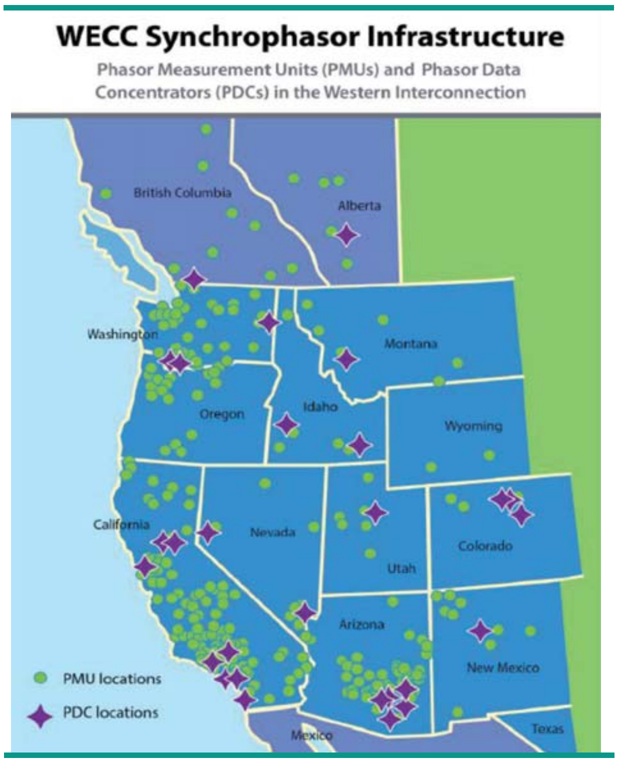


Figure 14: WECC synchrophasor infrastructure.

WECC's synchrophasor network (see Figure 14) is known as the Western Interconnection Synchrophasor Program (WISP). WISP is one of nine synchrophasor deployment grants awarded by the U.S. Department of Energy (DOE) Smart Grid Investment Grant (SGIG) program.[2] The grant is matched by funds from nine WISP partners who installed more than 390 new phasor measurement units (PMUs) and 60 phasor data concentrators (PDCs) throughout the Western Interconnection.[3]

Early in the project, all WECC balancing authorities executed a data sharing agreement. The data sharing agreement is critical to the exchange of synchrophasor data among transmission owners, operators, reliability coordinators, researchers, and vendors to promote development of the technology and applications. The agreement also shields these data from merchants and marketing functions, thereby ensuring the protection of market-sensitive information. A reliability portal—WECCRC.org—is live with restricted access available to transmission owners, transmission operators, and balancing authorities that have signed WECC's Universal Data Sharing Agreement. The portal includes a phasor registry, historical archives, wide-area view, next-day studies, and disturbance reports, all designed to improve the visibility and reliability of the bulk electrical system.

Bonneville Power Administration

Bonneville Power Administration (BPA), part of DOE, is a federal power marketing authority based in the Pacific Northwest. BPA markets wholesale electrical power from 31 federal hydroelectric projects owned and operated by the U.S. Army Corps of Engineers and Bureau of Reclamation, one non-federal nuclear plant, and some small non-federal resources. BPA supplies about one-third of the electric power used in the Northwest.

[2] More information on the DOE SGIG program can be found at www.smartgrid.gov.
[3] More information on the WISP partners can be found at https://www.smartgrid.gov/project/western_electricity_coordinating_council_western_interconnection_synchrophasor_program

BPA's service area includes Oregon, Washington, Idaho, western Montana, and small parts of Wyoming, Nevada, Utah, California, and eastern Montana (see Figure 15). BPA owns, operates, and maintains approximately 75% of the high-voltage transmission system in the region, and is a leader in integrating renewable resources, such as wind energy, into its grid.

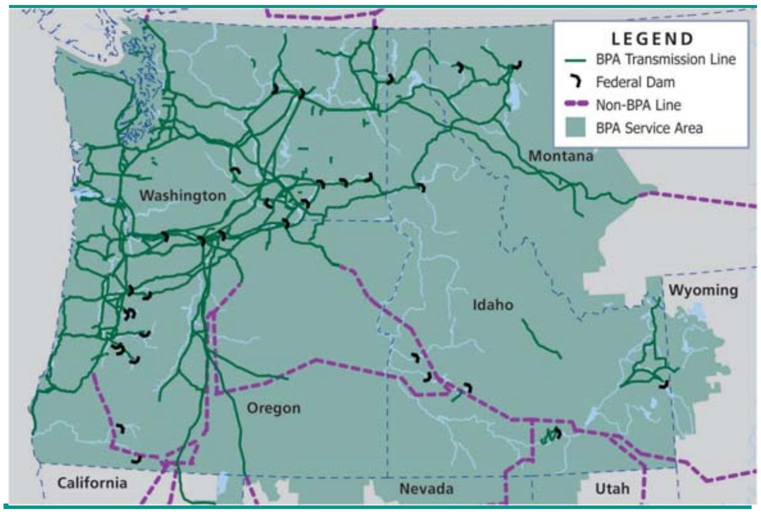


Figure 15: Bonneville Power Administration's transmission field service regions.

As a self-funding agency, BPA recovers its costs by selling wholesale power and transmission and related services at cost. BPA promotes energy efficiency and renewable energy. The agency is committed to public service and seeks to make its decisions in a manner that provides financial transparency and opportunities for input from all stakeholders.

BPA has been working to advance synchrophasor technologies for 20 years. In 1996, BPA was the first utility to assemble PMUs into a network and stream synchrophasor data from substations to its control center in real time. BPA also led the development of applications that use synchrophasor data. BPA built the largest synchrophasor system in the WECC project and is highlighted in this case study.

Objectives and Benefits

The synchrophasor project provides grid operators and reliability coordinators with more frequent and time-synchronized system information. Better system visibility will help system operators avoid large-scale regional outages, better utilize existing system capacity, and enable greater utilization of intermittent renewable generation resources. Benefits of the project are listed below.

Wide-area control

BPA developed dynamic response requirements for PMUs, tested their feasibility in its laboratory, and then encouraged leading manufacturers to adopt these requirements. As a result, a state-of-the-art device is on the market and available for other utilities. BPA is currently the only WISP partner planning to use wide-area synchrophasor measurements for wide-area controls.

Control room applications

Providing grid operators with a better view of power system dynamics is a key objective of this project. To that end, BPA engineers developed a suite of real-time analytical applications; the application engine processes about 18,000 PMU measurements every second in real time. BPA then deployed four state-of-the-art applications in its control center and developed operational displays. BPA will finalize alarming thresholds and operating procedures by the end of 2014.

Response-based controls

The BPA system was designed for response-based controls. The synchrophasor-based controls will use wide-area synchronized measurements to determine voltage stability risks and will initiate corrective actions in less than one second.

System model validation

Accurate power system models are essential for reliable and economical grid operations. Using data from system disturbances, BPA pioneered a new approach for validating power plant dynamic models. The agency's approach is cost-effective and less intrusive than traditional methods, which subject generators to staged tests. BPA has performed model validation assessments at 12 power plants (115 generators with a total capacity of about 20 GW). BPA is now expanding the model validation approach to wind power plants. BPA has installed PMUs at its four largest wind hubs and is working with DOE national laboratories and the Electric Power Research Institute to develop and validate dynamic models of wind generators. The agency is helping other utilities in North America to deploy PMU-based power plant model validation.

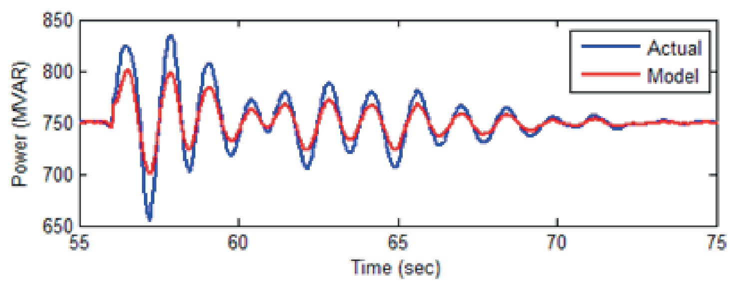


Figure 16: In 2009, Grand Couleea hydropower generator's response to an oscillation (blue) differed from the expected baseline response (red), helping engineers to determine that the power system stabilizer had failed.

Optimized capital investment

Project data have provided BPA with a better understanding of power grid performance, which leads to better decisions about the need and timing of capital investments in the transmission system. BPA expects to defer the need for $40 million in dynamic voltage control equipment over the next 10 years.

Large-scale outage avoidance

Synchrophasor data give an unprecedented view of power system stability issues, such as power oscillations that can lead to large-scale power outages. Under its synchrophasor program, BPA deployed mode meter and oscillation detection applications, which are expected to provide dispatchers with early warning of oscillation risks.

Compliance with regulatory standards

North American Electric Reliability Corporation (NERC) reliability standards and WECC policies require periodic validation of power plant models to assess power grid stability. BPA spends about $325,000 per year to comply with model validation regulations. The new model validation applications are expected to reduce that cost by at least $100,000 per year. Most significantly, the PMU-based model validation was used to calibrate the model of Energy Northwest's 1,100 MW Columbia Generating Station nuclear power plant. This prevented the need for a staged test, which would have cost the plant between $100,000 and $700,000, depending on the outage duration and cost of replacement power.

Early detection of equipment problems

Continuous monitoring of power plants led BPA to detect several control issues, such as failure of power system stabilizers at a Grand Coulee Dam generator (750 MW), Colstrip coal plant (800 MW), and McNary Dam generators (800 MW). BPA also detected persistent forced oscillations at a wind power plant. BPA's synchrophasor data are recognized as the best in the industry for quality and availability. BPA's synchrophasor network is redundant; two separate streams of data are available, one at each of the agency's control centers. If the PMU data at one control center are missing or erroneous, data from the other control center are automatically used, significantly increasing the overall quality of PMU data.

Technology

Synchrophasors are precise grid measurements taken from PMUs. PMUs measure voltages, frequency, current, active and reactive power, and stream measurements to a control center at 60 samples per second. Other utilities may use different sampling rates of 30, 120, or 240 samples per second. All measurements are time-synchronized to a microsecond using the Global Positioning System (GPS) timing system, providing an unprecedented view of the power system's dynamic state.

Early research and development (R&D) investments allowed BPA to develop the expertise it needed to turn its prototype synchrophasor network into a highly reliable, secure, and control-grade operational system. Under this investment, BPA installed 126 PMUs at 50 key substations and large wind generation sites.

BPA deployed sophisticated data management techniques to handle the unprecedented volume of real-time data now being collected. BPA also developed an application engine to analyze the data in real time and alert system dispatchers when the power system is at risk. In addition, BPA pioneered PMU-based power plant model validation, which is now recognized as a leading industry practice. BPA also designed a wide-area response-based control scheme that uses PMU measurements to assess the system and take necessary measures at multiple substations within less than one second of an initiating disturbance. This system is scheduled to go operational in October 2015.

BPA's synchrophasor project is at the leading edge of technology innovation and represents a clear break from previously established methods. The program combines the latest synchrophasor technology with a more robust telecommunications system to give transmission operators a much clearer view of the entire system in the West. With all the measurements synchronized by GPS, BPA can see precisely how the interconnected power systems in the West are responding to changes or disturbances.

Technology Benefits: For Industry and the Community

The project benefits the western United States by allowing for more power transmission without immediate build-out. For example, the California-Oregon Intertie (COI), a critical transmission pathway in the Western Interconnection, currently has an upper operating limit for power flow based on engineering studies. However, synchrophasor technology can provide real-time information and automated controls that, in time, will permit grid operators to raise operating limits on the COI and other constrained transmission paths. The synchrophasor technology can detect oscillations very quickly and activate capacitor banks to dampen these oscillations before they can grow to dangerous levels.

In addition, regional power systems have to evolve to account for new sources of supply (i.e., renewable energy), and this project facilitates integration of these sources (e.g., PMUs are needed for interconnection at wind farms). The short-term benefits to the community are clear, as are the longer-term benefits to the global climate.

The goal of this project, to improve transmission system reliability, extends to community safety as emergency and health services, for example, depend on stable power services. As noted above, the power plant model validation method allows energy providers to forego invasive tests on generators. Not only does this save providers—and ultimately end users—money, it also averts possible repercussions of such tests, such as damage to older equipment and safety hazards for staff conducting the tests.

UNITED STATES

Wide-area measurement systems used to avoid large-scale outages

Current Status and Results

In 2013, BPA completed installation of an unparalleled synchrophasor network, part of a three-year, $30 million investment. The agency is receiving data from 126 PMUs at 50 key substations and large wind-generation sites throughout the Northwest. In addition, BPA developed an application capable of assessing the dynamic performance of its generating fleet within minutes of a power grid disturbance.

BPA now has the largest, most sophisticated synchrophasor network of any utility in North America. It is the only fully redundant synchrophasor network in the West, and the only synchrophasor network designed with power system control capabilities in mind. BPA won a Platts Global Energy Award for this work. The award recognizes the organization that best drives opportunities and innovation that lead to significant increases in reliability, cost reduction, and operational efficiency.

BPA is sharing its developments with other utilities, encouraging the use of these technologies across the industry. BPA's investment in synchrophasor technology is expected to provide significant value to the agency, northwest electric utilities, and electric ratepayers.

Lessons Learned and Best Practices

Launching the first synchrophasor project of this scale and complexity presented new challenges. A project of this scale and complexity demanded collaboration between experts from several different fields. It took the proficiency and creativity of a multi-disciplined team, including experts in telecommunications, cyber security, power grid operations, control center hardware and software, network planning, and top-level project management. The team had two years to complete PMU designs and installations at 50 substations, many of which are critical 500 kV sites on the power grid.

In addition, each installation presented unique constraints, such as limited rack space for the new PMUs, the need for long cable runs for equipment connections, or the need to upgrade battery and charger systems. Coordinating the design, site surveys, construction, installations, and outage schedules required advanced project management skills. Examples of the lessons learned related to cyber security and data management applications are listed below.

Cybersecurity

Unlike most conventional control center data acquisition systems, which use point-to-point serial communications, the PMU network uses a routable protocol to stream data from substations to control centers. Because BPA will use the synchrophasor data for real-time control applications and operational decision making, the data must meet stringent cyber security requirements. The project team developed an innovative, comprehensive cyber security strategy, including the design and deployment of a system to centrally manage user accounts and passwords for the PMUs, which do not natively support that functionality.

Data management
BPA is now collecting 137,000 measurements from across the grid every second, pushing the capabilities of the existing commercial data systems to the limit. BPA had to develop intelligent data mining capabilities to make sense of the vast amount of data (more than half a terabyte) generated each month.

Applications
There were no off-the-shelf production-grade control room applications available to meet BPA's needs and requirements. Agency engineers chose an open architecture platform on which to develop and run a suite of fully customizable, real-time analytical applications and visualization displays.

Next Steps

BPA plans to continue to solicit ideas for R&D projects. The agency is collaborating with wind power plant operators in the region to expand PMU coverage. Currently, BPA has almost 5,000 MW of wind generation connected to its control area. PMU data will help address large-scale wind integration challenges. Challenges currently being addressed include dynamic control performance and model validation. Wide-area stability controls will be added in the near future.

To facilitate coordinated operation of the interconnection, BPA exchanges PMU data with 11 key partners in the region and will be expanding this exchange in the future. Figure 17 shows the PMU data flows in the North American Power grid.

UNITED STATES

Wide-area measurement systems used to avoid large-scale outages

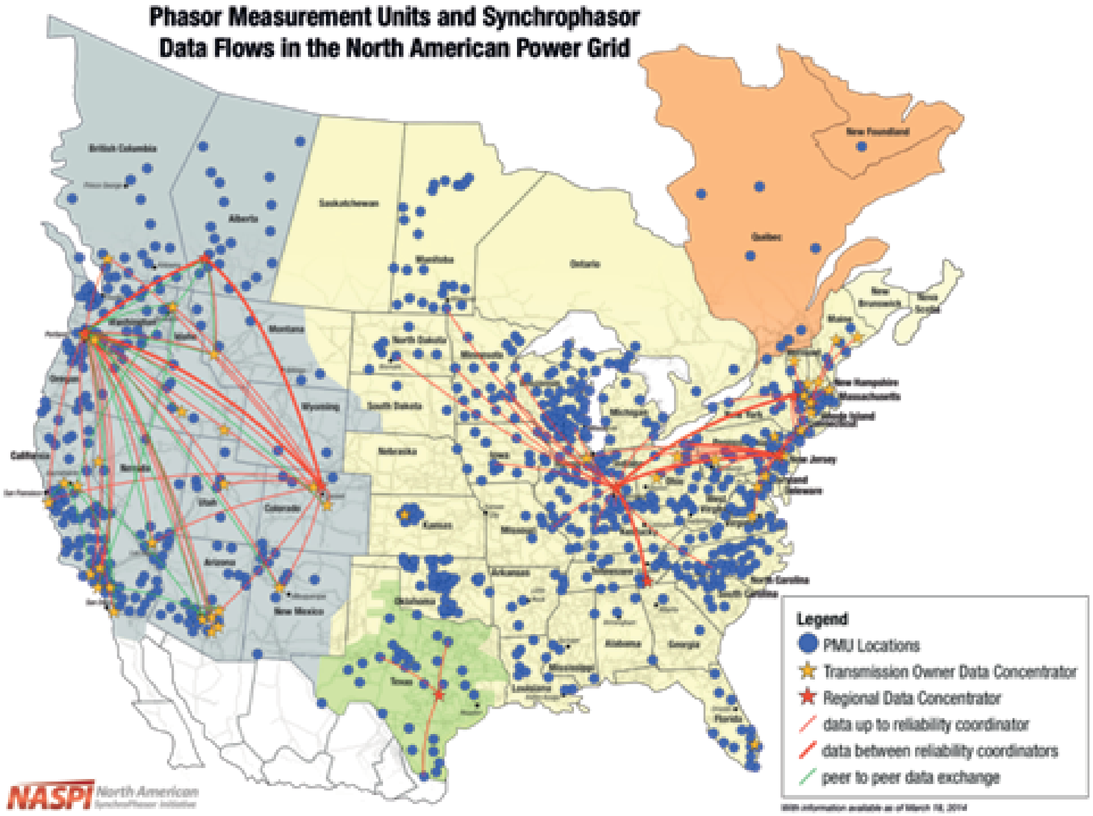


Figure 17: Data flows from transmission owners to regional hubs.

Another important area for future growth is the development and refinement of advanced applications. The vast synchrophasor network will provide grid operators and reliability coordinators an unprecedented view of the Western Interconnection and dramatically improve situational awareness. While PMUs and PDCs provide the data, advanced transmission software applications will help grid operators, reliability coordinators, and engineers use the new information that will flow in from across the Western Interconnection. The earliest applications will focus on monitoring grid conditions and disturbances. Such applications will include monitoring of system frequency, voltage, and oscillations. Other applications will utilize synchrophasor information to control devices in ways that have been impossible in the past. Some applications will allow engineers to improve power system models and increase the operational efficiency of the grid.

U.S. Department of Energy

DOE recognizes the critical need for advanced application development and is working on a phased approach for turning data into actionable intelligence. DOE is funding R&D for advanced applications in two principal areas:

- Real-time grid operations applications to provide wide-area visualization and increased state awareness
- Planning and off-line applications to improve system planning and analysis, including power system performance baselining, event analysis, and model validation

Figure 18 below outlines when these advanced applications are expected to be phased in over time.

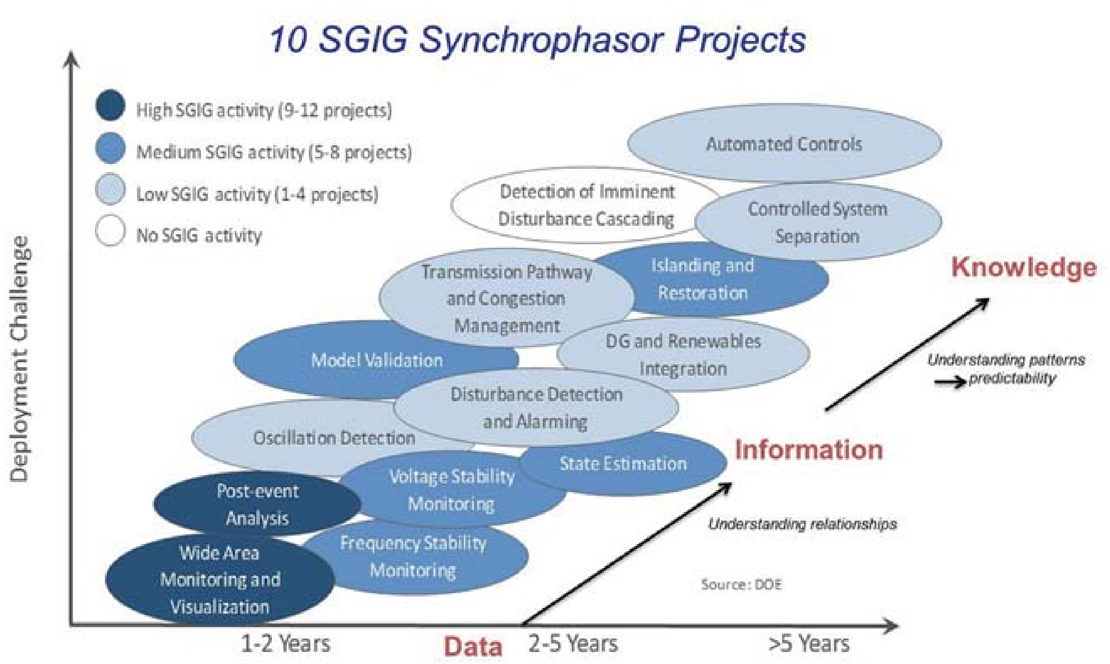


Figure 18: Advanced applications roadmap for the DOE SGIG projects.

UNITED STATES

Wide-area measurement systems used to avoid large-scale outages

SUMMARY: INTEGRATION OF SYNCHROPHASORS IMPROVES GRID OPERATION AND EFFICIENCY

What is the project about?

The Bonneville Power Administration (BPA) is a federal power marketing authority based in the northwestern part of the United States. In 2013, BPA completed installation of an unparalleled synchrophasor network, part of a three-year, $30 million investment. The BPA synchrophasor project combines the latest synchrophasor technology with a more robust telecommunications system to give transmission operators a much clearer view of the entire system in the West. With all the measurements synchronized by GPS, BPA can see precisely how the interconnected power systems in the West are responding to changes or disturbances.

Main goals

The project provides grid operators and reliability coordinators with more frequent and time-synchronized system information. Better system visibility will help system operators avoid large-scale regional outages, better utilize existing system capacity, and enable greater utilization of intermittent renewable generation resources.

Current status/timeline

The agency is receiving data from 126 Phasor Measurement Units (PMUs) at 50 key substations and large wind-generation sites throughout the Northwest. In addition, BPA developed an application capable of assessing the dynamic performance of its generating fleet within minutes of a power grid disturbance.

What is the result/expected benefits of the project?

The wide-area synchrophasor measurements are used for wide-area controls. The synchrophasor-based controls will use wide-area synchronized measurements to determine voltage stability risks and will initiate corrective actions in less than one second. Also, four real-time analytical applications are in use in the BPA control center together with operational displays.

Another important benefit is that the collected data is used to validate the system models leading to more accurate models, which are essential for reliable and economical grid operation.

The data gives a better understanding of power grid performance, which, in turns, leads to possibilities to optimize the capital investment. It is also expected that the synchrophasor data will lead to large-scale outage avoidance and early detection of equipment problems.

What's next?

BPA will continue to solicit ideas for research and development projects. The agency is collaborating with wind power plant operators in the region to expand PMU coverage, and PMU data will help address large-scale wind integration challenges. To facilitate coordinated operation of the interconnection, BPA exchanges PMU data with 11 key partners in the region and will be expanding the exchange in the future. Another important area for future growth is the development and refinement of advanced applications.

ITALY

Wide-area measurement enhances the Italian power system

Photo: NREL

ITALY	
Market Structure	The publicly listed company Terna owns and operates most of the transmission grid in Italy in the form of a natural monopoly. The distribution grid is managed by distribution system operators under a state concession regime.
Electricity Consumed (2013)	297,000 GWh
Peak Demand (2013)	53,942 MW
System Type	Synchronous European Grid (34 european countries connected)
Electricity Fuel Mix (2013)	Ratio: Thermal 72.4%; Hydro 17.8%; Other RES 9.8%
Installed Power (2013)	125,000 MW (net), 129,000 MW (gross)
Interconnection	Italy is interconnected to France, Switzerland, Austria, Slovenia, and Greece, and a new high-voltage direct current link is planned between Italy and Montenegro.
Number of PMUs	Fifty-five substations are monitored today. More units are expected to be installed, making a total of more than 100 units.
Contact	Diego Cirio RSE S.p.A. - Ricerca sul Sistema Energetico diego.cirio@rse-web.it Giorgio Giannuzzi TERNA giorgio.giannuzzi@terna.it

[1] This case was adapted from the full report available at http://onlinelibrary.wiley.com/doi/10.1002/etep.540/abstract.

ITALY

Wide-area measurement enhances the Italian power system

CASE

Project name:	**Wide-Area Measurement System Platform**
Leading organization:	**TERNA**
Ongoing since:	**Early 2000s**
Type of project:	**Commercial**

CASE HIGHLIGHTS

The development of Wide Area Measurement System (WAMS) technology, combined with phasor measurement unit (PMU) devices, offers ***new, valuable solutions for power system analysis, monitoring, and control.***

System dynamics are tracked in real time with high accuracy, which provides valuable benefits:

- Improves system-wide awareness and understanding
- Supports decision making and performance control

The availability of synchronized phasor measurements could ***mitigate or even prevent large disturbance scenarios.***

Introduction

Development of wide-area measurement system (WAMS) technologies, combined with phasor measurement unit (PMU) devices, offers new, valuable solutions for power system analysis, monitoring, and control.

After the initial applications—limited to offline studies, essentially for modelling and event reconstruction purposes—synchronised phasor measurements have become a reality in utility control rooms worldwide. Operators are able to track system dynamics in real time with a degree of accuracy and detail that was impossible with conventional supervisory control and data acquisition (SCADA) systems. This allows a deeper and more straightforward understanding of system conditions and provides considerable support for deciding and performing control actions and manoeuvring. Control rooms for nearly all transmission system operators (TSOs) in Europe are now equipped with a WAMS.

The first synchronised measurements in the Italian system were performed in the early 2000s, when preliminary tests with different commercial PMUs were carried out. Eventually, a single model was adopted for system-wide deployment. TERNA, the Italian transmission system operator, designed the communication and central processing system to address specific requirements while ensuring openness for future developments.

The WAMS developed in Italy consists of a set of PMUs, a dedicated data network, and computer systems for data processing and management, including monitoring applications and intelligent display at the National Control Center of TERNA in Rome.

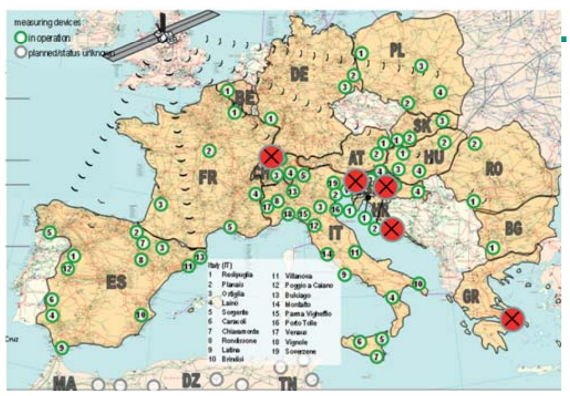


Figure 19: PMU deployment in continental Europe. Sites connected to the Italian WAMS are in red circles marked with "x."

The PMUs are installed at the major Italian transmission network substations. Currently, 55 substations are monitored by PMUs, mainly on the 400 kV level, but also on 220 kV and 150 kV. More sites can be monitored from the control room.

Real-time data exchange is performed with measurements from PMUs installed in other countries of the continental Europe interconnected system, affording wider operational awareness, by means of dedicated gateways. These countries include Croatia (power system operated by HEP), France (Corsica island, EDF), Greece (IPTO), Slovenia (ELES), Switzerland (Swissgrid), Denmark (Energinet), and Germany (Amprion).

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Wide-area measurement enhances the Italian power system

Objectives and Benefits

This project aims to provide new, valuable solutions for power system analysis, monitoring, and control. WAMS operators frequently react more promptly and appropriately to disturbances—the Union for the Coordination of the Transmission of Electricity (UCTE) report on the 2003 blackout in Italy explicitly recommended the development of a WAMS—and the availability of synchronised phasor measurements could mitigate, or even prevent, large disturbance scenarios.

The implemented monitoring functions in the Italian WAMS have yielded many benefits, including the following:

- Early warnings to operators in case of oscillatory behaviour of the system
- An increased capability to detect islanding conditions and network separation
- Important feedback regarding the tuning or repairing of devices in case of under-frequency load shedding
- The possibility to operate the lines closer to their limits (this function is currently under testing)
- The possibility to accelerate re-connections via real-time angle monitoring

Technology

Wide-area communication

The PMU data are sent to a central acquisition system. The interface with the other TSOs is implemented by a gateway/concentrator. The whole system is protected by a firewall.

Central system

The architecture of the WAMS platform at the National Control Centre consists of several processing tasks carried out in parallel on the server. Each task runs in real time to ensure high performances. The system is designed to accomplish tasks within different cycle times, and measures have been taken to ensure that tasks are synchronised and prevent a dangerous time drift of the system.

The basic activity of the WAMS platform is the acquisition and storage of the data packages sent by the PMUs to the control centre. The processing cycle time is set by the user, with the obvious lower limit of 20 milliseconds (i.e., the time required to get new data).

The system also features a virtual acquisition function—a sort of "field emulator"—which feeds the acquisition and storage activities with data coming from sources such as text files. This virtual acquisition function allows for the testing of the WAMS with critical situations of the power system, either recorded from the field or simulated, thus testing the monitoring and alarm functions. The field emulator represents a very important debug tool in the development and commissioning of the external processing functions.

Operator Interface

The WAMS has a dedicated operator interface at the National Control Centre of TERNA. It is currently not integrated in the energy management system, but works as an independent data source. The information visualised online for the operators includes plots and charts of PMU measurements and of data obtained by measurement processing, such as voltage magnitude and phase angle, frequency, stability indices, and alarms.

Figure 20 shows a typical geographic display of the WAMS platform. The map works as a dynamic colour map, displaying the value of a quantity selected by the operator: voltage magnitude, relative phase angle, or frequency. More detailed information is provided in the other graphic elements, such as the arrows between nodes, which show the direction of active and reactive power flows (blue and purple arrows respectively), and arrow thickness, which varies according to the angle difference between the nodes. Phase angle differences between the nodes are also explicitly marked.

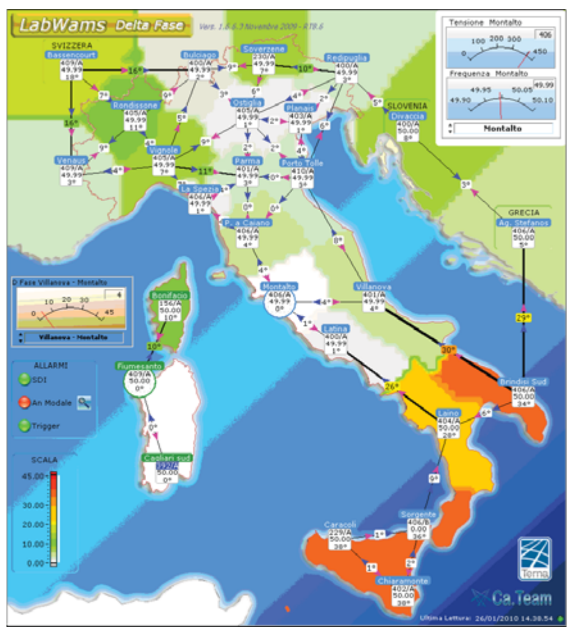

Figure 20: A typical geographic display of the WAMS platform. The background colours of the map depend on the voltage magnitude.

Together with the geographic display, other visualisation and control displays can be shown (e.g., plots of voltage magnitude evaluation or results of the oscillatory analysis function). Other displays contain configuration data, such as visualisation options and alarm threshold settings. Specific alarms are automatically triggered on occurrence of threshold violations (e.g., in the case of high/low voltage magnitude).

Monitoring Functions

Oscillatory analysis

Oscillatory stability is a concern, especially for the risk of undamped inter-area oscillations throughout large interconnected systems. The Italian system participates in the oscillatory modes of the continental European system, and may experience internal oscillations, typically between North and South due to its longitudinal structure.

Algorithms have been developed to evaluate the oscillatory stability from measured data. The resulting early warning ensures that a suitable margin of time is available to decide and implement control actions.

The oscillatory analysis algorithm can be used both in real time applications and for offline purposes, such as the validation of generator power system stabiliser (PPS) settings and the identification of the need for PPS re-tuning. If sustained oscillations jeopardise system security, the control room operators can take actions such as reducing the stress associated to the active power transfer from the affected area.

Islanding detection

An important aspect in severe disturbance scenarios consists of, following an uncontrolled cascading, promptly understanding if the system has split into electrical islands and what is the composition of those islands. This task—not trivial with ordinary monitoring and analysis tools—spurred development of a WAMS algorithm to detect network separation conditions. The algorithm identifies the number and composition of all the electrical islands monitored by the PMUs, and identifies the areas that are physically still connected, yet have started to operate "asynchronously" due to an ongoing loss of synchronism.

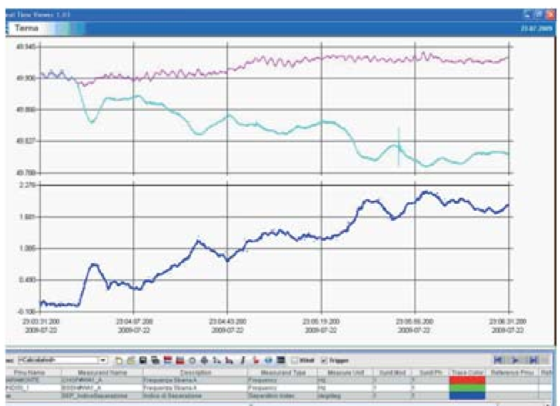

Figure 21: Application of the algorithm for the detection of network separation; the increasing separation index (bottom curve) denotes that the system has split into islands.

Load shedding intervention detection

To inform operators about the expected intervention of the under-frequency load shedding devices, a model of the load shedding devices installed in the field was implemented. The objectives of this function are both for online and offline purposes: Online, the operator is rapidly warned that a frequency transient exceeding the load shedding device threshold has occurred; subsequently, operators can check whether the relays have actually operated. This feedback is important to identify the need for repairing or re-tuning devices that did not behave as expected.

Line temperature estimation

One of the most interesting and innovative applications of PMUs is the real-time monitoring of the line temperature. Line rating is generally computed by conservative, offline evaluations based on the worst expected conditions (i.e., winter/summer rating). However, more accurate evaluations would make it possible to identify potentially dangerous situations in time and to exploit the actual limits of the assets. The advent of PMUs suggested a fast and cost-effective method to evaluate the average temperature of the lines.

The testing campaign conducted so far showed that the line temperature estimation algorithm is effective (it should be noted that the measured temperature is an average one; hot spots cannot be identified). Within a wider project aimed to test several Dynamic Line Rating (DLR) techniques, the technique based on PMUs has been complemented by the installation of sensors to measure line temperature at specific points, as well as to retrieve weather data. The aim is to define an approach to combine, in the most effective way, the information coming from the different sources. Currently, five lines are being monitored by this experimental application.

Real-time angle monitoring as a support to manoeuvring

Reconnection of electrical islands or of electrically distant areas within an interconnected system is a task where the real-time angle measurements provide highly valuable support. For example, during the reconnection following a separation between the Italian and Slovenian grids, angle visualisation proved helpful in accelerating the procedure by providing a real-time feedback of the preparatory control actions.

Technology Benefits: For Industry and the Community

For the selection of the initial PMU locations, several complementary approaches were developed, resulting in combined heuristic-analytical criteria. Each criterion concerned local or system aspects regarding event identification, oscillation detection, angle, voltage, and frequency stability monitoring. The operators' experience pointed out a number of heuristic criteria (e.g., proximity to large generating units, bottlenecks, system boundaries, etc.) that were also taken into account. The future installations are primarily meant for monitoring of critical interfaces of the grid.

ITALY

Wide-area measurement enhances the Italian power system

Current Status and Results

Since the mid-2000s, the WAMS platform has provided valuable support to operators in the control room. Real-time plots and charts of system quantities, such as phase angle differences, and the output of monitoring functions, such as oscillation identification, enable operators to better track system stress and dynamic phenomena, and evaluate manoeuvre viability. Cooperation with other countries of the same synchronous area, in the form of real-time PMU data exchange, proved particularly useful.

Currently, 55 substations are monitored by PMUs, mainly on the 400 kV level, but also on the 220 kV level. Substations at 150 kV have been equipped with PMUs as well, especially in the areas with limited coverage of 400 kV and in view of testing DLR applications. More PMUs are expected to be installed in the near future, for a total of about 100 units.

Overall, the following monitoring functions are currently implemented and in operation in the Italian WAMS:

- Oscillatory analysis
- Islanding detection
- Load shedding intervention detection
- Real-time angle monitoring

Line temperature estimation is currently under advanced testing.

Lessons Learned and Best Practices

Experience with the WAMS spans hardware (e.g., field installation of the PMUs) to software (e.g., algorithms of the monitoring functions). Lessons learned to date include:

- Fine tuning the error compensation functions for current transformers (CTs) and potential transformers (PTs) installation at field level is very important
- Proper management and monitoring of the communication channels are vital for an effective response of the system

- Field testing has shown that not all commercial PMUs correctly inform the remote centres about malfunctions, such as loss of time synchronisation or communication problems.
- An open issue is the rate of data exchange: A large number of TSOs would set a periodicity of 100 ms, because that is sufficient to monitor most electromechanical phenomena. However, some monitoring functions need a tighter periodicity (e.g., 20 ms), which is necessary for the load shedding intervention detection function.
- The WAMS platform has been available in the control room of TERNA initially with elementary display functions, then with more advanced visualisation techniques and enhanced monitoring functions. The monitoring functions require a long tuning and testing phase before they become a reliable support in the control room. However, overall the operational experience is highly positive.
- Offline analyses help engineers understand dynamic phenomena, evaluate power system component performances, improve modelling, and carry out more accurate event reconstruction.
- Online monitoring applications provide the operators with important support under all operating conditions, from normal to restoration. In particular, the colour map display has been very much appreciated in the control room.

The main advantages recognised by the operators regard the possibility to achieve the following:

- A synthetic overview of the whole system, independent of the SCADA.
- A straightforward identification of the problems.
- A greater awareness about the angle differences as representative of power transit between zones.

Among the advanced monitoring functions, the load shedding intervention detection has been very useful in several practical occasions. It proved helpful for improving operational awareness in disturbance situations and validating the correct operation of the under-frequency relays. The function was also used in offline analyses to identify the need for on-the-field device repair or re-tuning. For example, during a frequency disturbance, the function showed that the protection failed to trip a pumped-storage unit, thus making it possible to detect a failure in the local relay.

An interesting episode of the oscillatory analysis function consists of a case of low damping, which occurred on several occasions and was detected by the oscillatory analysis function. Subsequent investigations showed that the PSSs of the power plants were ill-set.

A by-product of the oscillatory analysis function consists of a sort of event detection functionality; events in the system abruptly change the value of the computed damping, thus setting off an alarm. The operator is therefore warned—within few seconds and independently of the SCADA—that an event occurred in a certain area.

Finally, with very low settings of the triggering thresholds, dynamic phenomena that cannot be normally observed have been identified, with accurate analyses of transient recordings.

Next Steps

Future PMU deployments will address critical interfaces of the grid. When each border is fully monitored, estimation of the state “by areas” may be investigated as a new monitoring function. Further perspectives regard the design of wide-area control systems/wide-area protection system solutions, coordinated and integrated with the existing Italian defence plans and shedding schemes.

The central processing system will be enhanced with a distributed architecture that will ensure greater reliability and allow the system to manage the increased amount of data resulting from PMU deployment.

Currently, the system relies on two servers: one of which hosts all the WAMS functions, while the other has the task of providing hot backup. In the future, different functions will be virtualised on different machines, improving computation performances and reliability. Hot backup will still be ensured by backups of the individual functions.

SUMMARY: ARCHITECTURE, FUNCTIONS, AND EXPERIENCES FROM THE DEVELOPMENT OF WIDE-AREA MEASUREMENT IN THE ITALIAN POWER SYSTEM

What is the project about?

The development of wide-area measurement system (WAMS) technology, combined with phasor measurement unit (PMU) devices, offers new, valuable solutions for power system analysis, monitoring, and control. This case study describes the architecture, monitoring functions, and operational experiences of the WAMS realised by TERNA, the Italian transmission system operator, for the synchronised monitoring of the Italian power grid interconnected with the Continental European system.

Main goals

The development of the Italian WAMS allows a deeper and more straightforward understanding of system conditions and provides considerable support to control actions and manoeuvring.

Current status/timeline

The first synchronised measurements in the Italian system were performed in the early 2000s, during preliminary tests of different commercial PMUs. Currently, 55 substations are monitored by PMUs, mainly on the 400 kV level, but also on the 220 kV level. Substations at 150 kV have been equipped with PMUs too, especially in areas with limited coverage of 400 kV and in view of testing Dynamic Line Rating applications. Functions have been developed for oscillatory stability analysis, network separation detection, load shedding intervention evaluation, and line thermal estimation. The development of real-time functions is still ongoing, potentially to include wide-area control systems/wide-area protection systems.

What is the result/expected benefits of the project?

The WAMS platform provides valuable information to support operators in the control room . Real-time plots and charts of system quantities, such as phase angle differences, and the output of monitoring functions, such as oscillation identification, enable operators to better track system stress and dynamic phenomena and evaluate viability of responses. Cooperation with other countries of the same synchronous area, in the form of real-time PMU data exchange, proved particularly useful.

What is next?

More PMUs are expected to be installed in the near future, for a total of about 100 units. Future PMU deployment will address critical interfaces of the grid. When each border is fully monitored, estimation of the state “by areas” may be investigated as a new monitoring function. Other anticipated activities include the design of WACS/WAPS solutions, coordinated and integrated with the existing Italian defence plans and shedding schemes. The central processing system will be enhanced with a distributed architecture that will ensure higher reliability and allow the system to manage the increased amount of data that will result from further PMU deployment.

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SOUTH AFRICA

Eskom: Grid situational awareness proof-of-concept

Photo: Stockphoto

<table>
<tr><th colspan="2">SOUTH AFRICA</th></tr>
<tr><td>Market Structure</td><td>Eskom is the primary electricity supplier of Southern Africa</td></tr>
<tr><td>Electricity Consumed (2014)</td><td>224,000 GWh</td></tr>
<tr><td>Peak Demand (2014)</td><td>34,000 MW</td></tr>
<tr><td>System Type</td><td>South Africa has a synchronous power system</td></tr>
<tr><td>Electricity Fuel Mix (2014)</td><td>
<table>
<tr><th></th><th>Production</th></tr>
<tr><td>Hydro</td><td>600 MW</td></tr>
<tr><td>Pumped Storage</td><td>1,400 MW</td></tr>
<tr><td>Nuclear</td><td>1,800 MW</td></tr>
<tr><td>Gas Turbines</td><td>2,400 MW</td></tr>
<tr><td>Coal</td><td>35,800 MW</td></tr>
</table>
</td></tr>
<tr><td>Installed Power (2014)</td><td>42,000 MW</td></tr>
<tr><td>Interconnection</td><td>Tie-lines connect the South African grid to neighbouring countries: Namibia, Botswana, Zimbabwe, Mozambique, Swaziland, and Lesotho</td></tr>
<tr><td>Contact</td><td>Oswald van Ginkel
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Renier van Rooyen
Eskom Holdings SOC Ltd, RT&D, Smart Grids
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</table>

SOUTH AFRICA

Eskom: Grid situational awareness proof-of-concept

CASE

Project name:	**Grid Situational Awareness-Visualisation Platform**
Leading organization:	**ESKOM**
Commissioning year:	**2013**
Type of project:	**Proof of Concept**

CASE HIGHLIGHTS

Investigate the feasibility, requirements, and development of a ***Visualisation Server stack*** to improve the ***grid situational awareness***

The system will ***provide real-time support for intelligent decision making*** and ***improve the efficiency of the following tasks:***

- Maintenance scheduling
- Preventative maintenance
- Fault-finding

Additional benefits include:

- Reduced downtime
- Immediate feedback based on data, including warnings of impending danger

Introduction

Situational awareness requires the ability to accurately anticipate future problems of the interconnected electrical power system and environmental conditions to enable effective mitigation actions.

Grid situational awareness provides real-time support for intelligent decision making based on real-time event management, forecasting, power stability, and management through dynamic system sources.

This project's proof of concept (POC) focuses on integrating various data sources to enable Eskom, the Southern Africa utility, to make smart decisions regarding situational awareness based on experience built up through the implementation process.

This project provides operational data and integrates geographic information systems (GISs) with historic data.

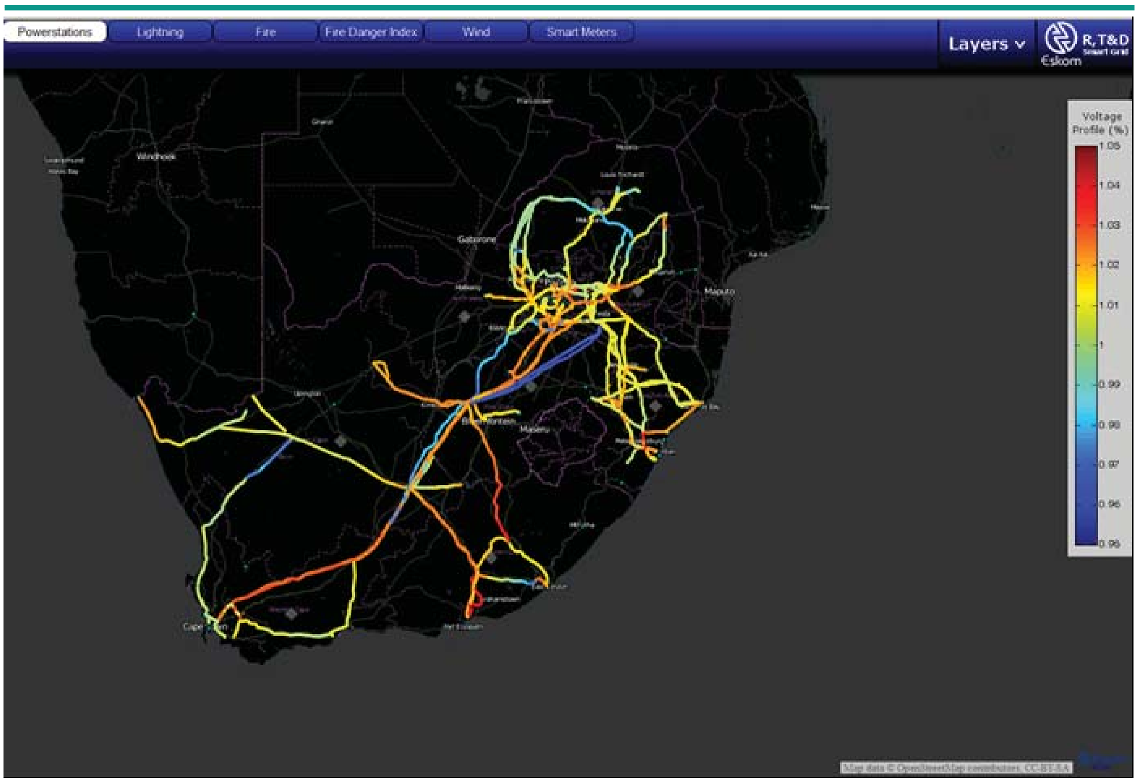

Figure 22: Visualisation of GIS data aggregated from the South African T&D system.

The completion of the POC entailed integrating various live data sets onto a central visualisation platform. Investigations were conducted to classify the data sources according to the following questions:

- Where is the current data residing?
- Who is responsible for the data?
- How did said person(s) store the data?
- In what format is the current data?
- How may said data be accessed?
- How is said data integrated?
- How may you visualise said data?

After the meta-data had been gathered, work focused on integrating the data sets into the visualisation platform where the following questions had to be answered:

- How will the data be displayed?
- What groups of data should be displayed together?
- What visualisation functionality can be implemented on the data layer in question?

The physical integration process was completed in three months. Most of the project's one-year timeline was spent collaborating with different providers of data, possible users of the data throughout the business, and system architects in order to establish a roadmap for future implementations regarding the integration and visualisation of data from disparate sources.

The main purpose of this research is the development of a centralised visualisation server platform. This work includes evaluation of geospatial and historian software, integration of data sources, and creation and demonstration of a visualisation server. Weather data, such as lightning and fire data, and supervisory control and data acquisition (SCADA) data are to be integrated on the same platform. Limitations and findings will be noted.

Objectives and Benefits

The overall goal is to improve the situational awareness in the Eskom system, and the described POC aims at investigating the feasibility, requirements, and development of a visualisation server stack. The visualisation server functionality was to be demonstrated upon completion of this POC.

The following key questions are addressed:

- How effective were the visualisation tools used?
- How can lightning data be interfaced?
- How can fire data be integrated?
- What software is necessary to implement a visualisation server?
- What technologies can be leveraged to enable visualisation?
- What is the maximum speed that can be achieved when interfacing each data source to a common visualisation platform?
- How effective are the current interfaces for enabling visualisation?
- What are the capabilities of the relational data storage systems enabling visualisation?
- Can snapshots of GIS data be utilised in conjunction with an historian database, and how?
- How can wind data be imported and visualised?
- How can transmission voltage profiles be visualised effectively?
- What are the limitations of using the web-based HTML5 GIS platform?
- How can data from distributed fault loggers be integrated into the historian platform?
- How can data displays be efficiently added to extend the GIS visualisation platform?

All of the following benefits and cost benefits will be realised once the research outputs of this POC are integrated into a fully fledged large-scale project:

- Learning from past experience: All of the lessons learned within this POC will be available to other projects, such as the Wires Visualisation project, to fast track development on their systems.
- Improved maintenance scheduling: Assets that are being overused can be identified, and they can be targeted for more routine maintenance, thus improving their life cycle.
- Preventative maintenance: Immediate determination of an asset entering an abnormal state helps avoid interruption of supply to the customer while speeding planning and execution of preventative maintenance.
- Fault finding: This system will monitor the individual health status guidelines and general health rules, reporting any anomalies and predicting the type of fault at work.
- Warnings of impending danger: Should a natural disaster or disturbance threaten the utility's assets, the system will warn the operators in advance, allowing preventative action to be taken.
- Shortened downtime: Because faults are anticipated via this system, the duration of time a customer will be disconnected from the grid will be minimised due to preemptive (rather than reactive) maintenance.
- Immediate feedback based on data: Any weather anomaly identified by this system or faults generated by assets will provide immediate feedback to the applicable personnel for action to be taken.

Technology

Data interfaces include SCADA Data Gateway solutions, customised implementations for loading some data sources via ASCII files into the historian, Telnet feeds, and the Open Geospatial Consortium Standard interfaces in the GIS environment. Linking to remote databases by using an object linking and embedding database (OLE DB) was also investigated.

Support for access protocols of data, such as representational state transfer (REST) and simple object access protocol (SOAP) web services and standardised formatting of the data, were considered.

The use of a "big data" approach, where the data storage is separate from the data hierarchy and structure, was utilised in the approach to make the data management simple and to easily allow automated and scheduled synchronisation of updated data windows to the visualisation platform.

The data processing algorithms were graphically modelled and implemented on a schedule.

Workforce Engagement

Throughout the process the various stakeholders within a utility landscape were identified and liaised with in order to maintain a concise and clear vision. This included regular working groups and technology forum demonstrations to instigate a feedback loop into how effective visualisation can be achieved. The following departments were identified and involved in the process:

- Information technology
- Engineering
- GIS
- Management
- Grid operations
- External data suppliers
- Distribution
- Transmission

Current Status and Results

To summarise, the following list of tasks and activities were delivered as part of this research POC:

- Providing data source drivers and interfaces for the following data sources (September 2013–October 2013):
  > SCADA Data concentrators
  > Digital fault recorders
  > Lightning data
  > Grass fire data
- Conducting the loading, linking, and visualising of the one-line substation diagram with the following key performance indicators (November 2013):
  > Real-time network status (e.g., with breaker, transformer status, voltage)
  > Transformer, lines, and bus bar loading
  > Lightning and fire
  > Protection information for plant abnormal status
- Obtaining object models for substation objects, their specific attributes, and the methods to configure or access said attributes
- Proving that various Eskom-specific data sources can be integrated on a visualisation interface and define appropriate methodologies to do so
- Obtaining feedback from the system operator regarding the transfer of developed capabilities into a maintained production environment during the closing phase of the 2013/14 financial year

Lessons Learned and Best Practices

Regarding the GIS platform, the following is of note:

- Managing of changes made to the JavaScript libraries must include proper testing on a variety of browsers utilised to access the data. The porting of the libraries has to be managed effectively from development through the ultimate production system.
- The OLE DB protocol is functional in importing historian data into the GIS environment, but may be regarded as inefficient especially because of the maintenance and work required for adding additional data sources.
- A streamlined interface between the historian platform and the GIS platform needs to be tested to document its flaws, shortcomings, and triumphs. This may effectively replace much of the functionality currently addressed through OLE DB protocol and related SQL scripts to process the data. This may, therefore, potentially simplify the integration of additional data sources.

The use of HTML5 provides an effective way to address a variety of mobile and desktop platforms and allow the platform the independence required from a business software architectural perspective.

The OLE DB protocol did present some reliability problems, especially when importing large quantities of data windows for visualisation.

The tested historian system is able to store lightning data. The efficiency of the storage, however, is lacking in the following way:

- The lightning may possibly occur more frequently (monitored at 1ns periods) than the storage resolution supported (15.28 µs). However, there may only be a limited number of cases where a lightning strike actually occurs in 15.28µs since the previous strike.
- The processing of large data sets of lightning is evidently slower than that of other data streams as evident from the average completion time around six minutes, and there may be cases where this processing can last up to an hour. Optimised processing and filtering might slightly enhance the speed of this asynchronous data source in particular.

It will be important that standard compression settings are specified for the various typical substation and other data inputs to the historian. This will ensure uniform data integrity throughout all datasets and enforce the reliability of the standard comparison of data.

It is advisable to use template data tags to simplify automatic creation of tags on the time series historian.

Antivirus and firewall systems utilise protocols that may negatively affect the interoperability of the various systems, and proper testing and configuration is required between data interfacing compute and buffer nodes and the historian.

Next Steps

Eskom renewable generation and independent power producers (IPPs) are severely impacted in terms of output capacity when dealing with weather conditions. This will produce severe imbalances should this generation capacity suddenly diminish due to pressing weather conditions. Future work will seek to inform the system operator of changes in forecasted load on renewables so the appropriate mitigating actions can be taken to restore balance to the grid.

The following list describes the planned high-priority outputs for continued research on grid situational awareness. The focus is especially on integrating data and implementing models related to forecasting renewable generation capacity.

- IPPs
  - > Generating capacity
  - > Forecast data
  - > Plan Load
  - > Audit IPP MW generated
- Home renewables market
- Predicting impact on the grid
- Pollution data
- Plant growth and vegetation
- Expanding and implementing visualisation and alerting rules

SUMMARY: ESKOM PROVIDES REAL-TIME SUPPORT FOR INTELLIGENT DECISION MAKING

What is the project about?

The project is about grid situational awareness (i.e., the combination of the electrical interconnected power system with environmental conditions in order to accurately anticipate future problems to enable effective mitigation actions). Grid situational awareness provides real-time support for intelligent decision making based on real-time event management, forecasting, power stability, and management through dynamic system sources.

The proof-of-concept focuses on integrating various data sources in order for Eskom, the South African utility, to be able to make intelligent decisions regarding situational awareness based on experience built up through the implementation process.

Main goals

The main goal is to improve the situational awareness in the Eskom system, and the described proof-of-concept aims at investigating the feasibility, requirements, and development of a visualisation server stack for the grid situational awareness concept.

Current status/timeline

The physical integration process was completed in three months. Most of the project's one-year timeline was spent collaborating with different providers of data, possible users of the data throughout the business, and system architects in order to establish a roadmap for future implementations regarding the integration and visualisation of data from disparate sources. Feedback was provided by the system operators regarding the transfer of developed capabilities into a maintained production environment during the closing phase of the 2013/14 financial year.

What is the result/expected benefits of the project?

Some benefits to grid situational awareness include the following:

- Improved maintenance scheduling
- Ability to perform preventative maintenance
- Fault finding
- Warnings of impending danger
- Shortened downtime
- Immediate feedback based on data

What is next?

The focus of the continued research on grid situational awareness is on integrating data and implementing models related to forecasting future renewable generation capacity and informing the system operator of drastic changes. Other data sources include pollution data and plant growth and vegetation. There are also plans to expand on visualisation and alerting rules.

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FRANCE

Smart Substation

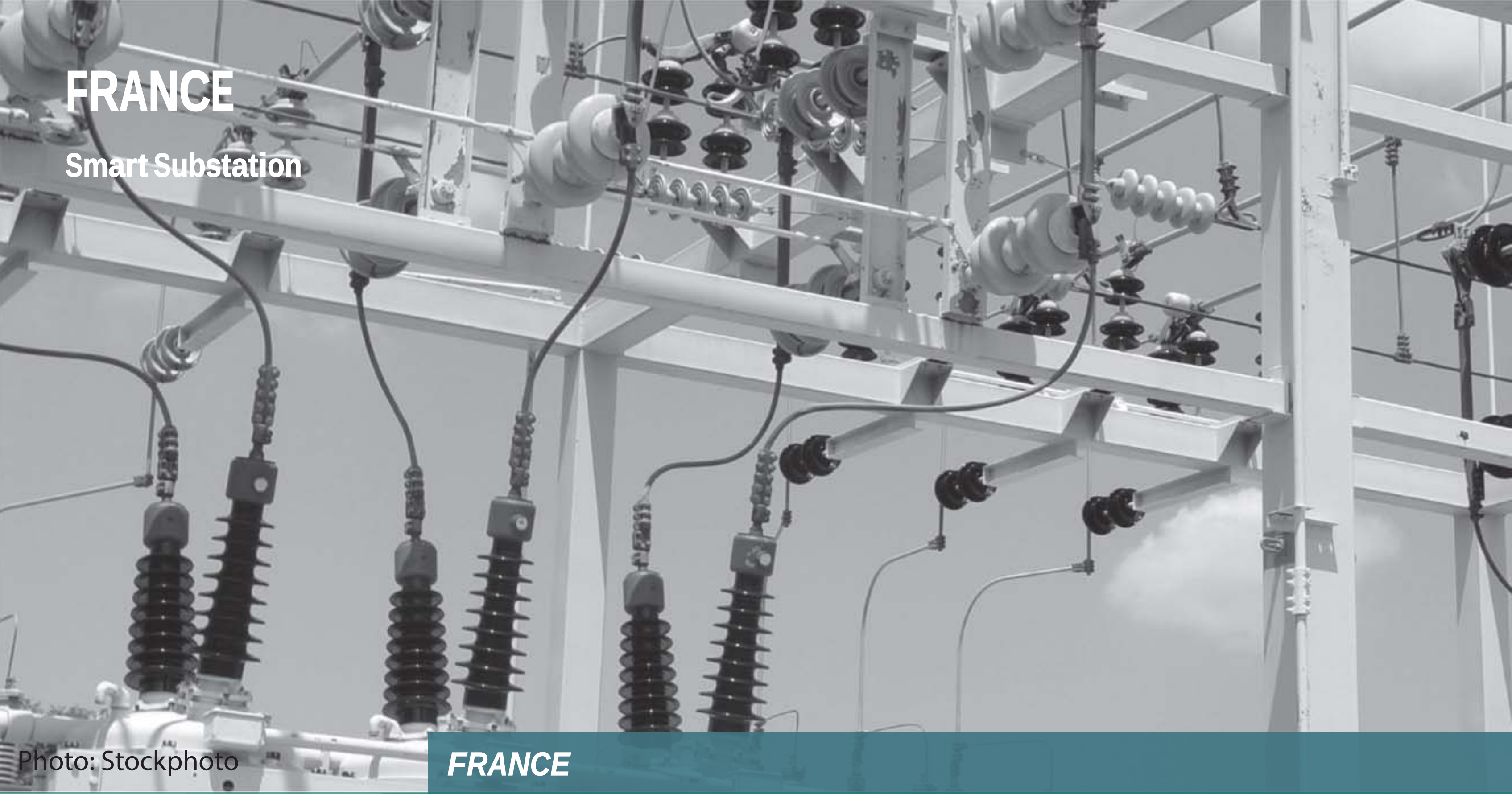


Photo: Stockphoto

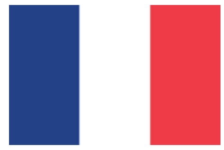
FRANCE

Market Structure	One transmission company (RTE), 21 distributing companies (the major one, ERDF, covering 95% of the consumers). Market opened to all consumers, feed-in tariffs for RES.
Electricity Consumed (2013)	476.200 GWh
Peak Demand (2013)	92,600 MW
System Type	Synchronous European Grid (34 European countries connected)
Electricity Fuel Mix (2013)	see table below
Installed Power	128.600 MW
Interconnection	With 100,000 km of lines from 63 to 400 kV, almost 2,700 substations and 46 crossborder lines to Spain, Germany, Italy, Switzerland, Belgium, and Great Britain, the network owned and operated by RTE is the largest in Europe.
Contact	BENA Michel, SmartGrids Director RTE Michel.bena@rte-france.com

Electricity Fuel Mix (2013):

	Production	Ratio
All	550.9 TWh	100%
Nuclear	403.7 TWh	73.3%
Coal	19.8 TWh	3.6%
Fuel	5.4 TWh	1%
Gas	19.5 TWh	3.5%
Hydro	75.7 TWh	13.8%
Wind	15.9 TWh	2.9%
PV	4.6 TWh	0.8%
Other RES	6.3 TWh	1.1%

FRANCE
Smart Substation



CASE

Project name:	**Smart Substation**
Leading organization:	**RTE**
Commissioning year:	**2016**
Type of project:	**Industrial pilot**

CASE HIGHLIGHTS

The smart substation solutions will provide the following benefits:

- Reduced environmental impact
- Improved integration of renewable energy
- Increased transmission capacities
- Optimised use of the existing asset

The smart substation solutions will achieve those benefits through the following mechanisms:

- Full digitalization of all links between the high-voltage equipment and the intelligent electronic devices
- Development of an open architecture (IEC 61850) that allows high-level system functions like local state estimation, local analysis and diagnosis of incidents, and auto-adaptive protection schemes
- Implementation of sensors and monitoring to optimize system operation and maintenance (e.g., dynamic line rating and preventive maintenance)

Introduction

The development and integration of distributed generation, especially renewable energy sources (RES), and changes in the consumption habits from new uses and active consumers, push the transmission and distribution system operators to adapt their assets to operate nearer to their physical limits. These changes also increase the transit capacity. Ongoing evolution of system operation and control is necessary to preserve, if not increase, quality of service in respect of economic constraints.

Transmission system operators (TSOs) and distribution system operators (DSOs) face the challenge of optimising T&D systems with strong constraints on the assets. Because of environmental pressure and social acceptability, it is much more difficult today to build new overhead lines (OHLs), underground cables, or substations. One way to deal with this is to bring new operating functionalities to the existing grid.

The Smart Substation project is an industrial pilot project of a new technological package, bringing advanced control functionalities to the French electrical grid. The project aims to bring new, digitalised functionalities of the electrical substation to the ultra-high-voltage grid, while considering the interface with the distribution grid.

The project will design, build, test, and operate a package of innovative components in smart substations under operating conditions and assess the technical and economical benefits for the electrical system (from economic, environmental, and security points of view).

The four-year project began in 2013; the first three years will be dedicated to technology development and the final year to experimentation. The demonstrations will be set in the north of France where there is significant wind power and where a many new wind parks are planned. Two types of substations will be developed and tested—a transmission substation and a distribution substation—which represent the interface between the transmission system and the distribution system. The innovative digitalised architecture will be deployed on existing substations.

The project, financially supported by the French government, has an overall budget of €32 million, and was developed through a consortium led by RTE. Members of the consortium are ERDF, Alstom Grid, Alcatel Lucent, Schneider Electric, and the start-up Neelogy.

FRANCE
Smart Substation

Objectives and Benefits

The Smart Substation project aims to design, build, test, and operate two fully digital smart substations in the northern area of France. Innovative solutions will be implemented and tested in real operating conditions with appropriate cyber security measures.

The project will assess the benefits provided by these solutions, such as a lower environmental impact, better integration of renewable energies, improved transmission capacities, and optimal use of the existing assets.

The main scientific and technical objectives include the following:

- Full digitalisation of all links between the high-voltage equipment and the Intelligent Electronic Devices (IEDs)
- Development of an open architecture (IEC 61850) that provides a standardised interface for high-level system functions, such as local state estimation, local analysis, and diagnosis of incidents, and an auto-adaptive protection scheme
- Implementation of sensors and monitoring to optimise system operation and maintenance (e.g., dynamic line rating [DLR] and preventive maintenance)
- Implementation of a digital interface between the TSO and DSO
- Full redundancy for relays and telecontrol

At a national scale, a transmission system using smart substations carries more energy than a traditional grid. Smart substations will enable the electrical power equipment to safely operate closer to physical limits. The development of digitalisation will optimise the grid's reinforcement works. At stake is *The Ten Year Network Development Plan*, compiled at the ENTSO-E level, which estimates that these reinforcement works are worth €50 billion in Europe.

The digitisation of all substations will also contribute to successful realization of the European commitment to increase RES integration.

Technology

Compared to the existing analog or semi-digital architectures, which are proprietary and closed systems, the most important change in the technological scheme will be the open system architecture. This will enable the connection of new equipment and allow for the implementation of new functions, thanks to middleware and a new generic database. These advanced functions will enable real-time knowledge of the state of the grid.

This project will also accelerate restoration by improving control of technical hazards and increasing the possibility of carrying out operation and maintenance from afar. These developments hinge upon two additional constraints: interoperability and cyber security. They will be based on the international standard IEC 61850 and will enable its enrichment.

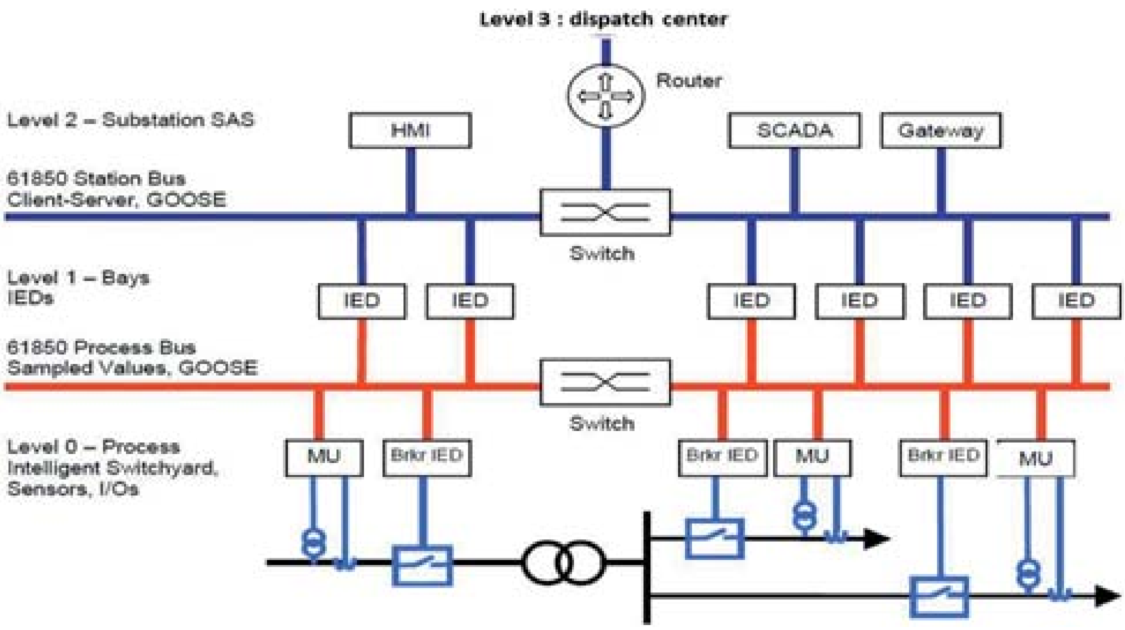


Figure 23: Technology integration in the Smart Substation.

Thus, technical challenges can be summarised by the following:

- Fully digital connection (optical fibre) between primary equipment and control-command systems
- IEC 61850 full compliance on the process bus, on the station bus, and between the substations
- Interoperability
- New approach for system redundancy and implementation of functions in the IEDs
- A global solution addressing all the present and future requirements based on an evolutionary approach
- Information and communications technology integration

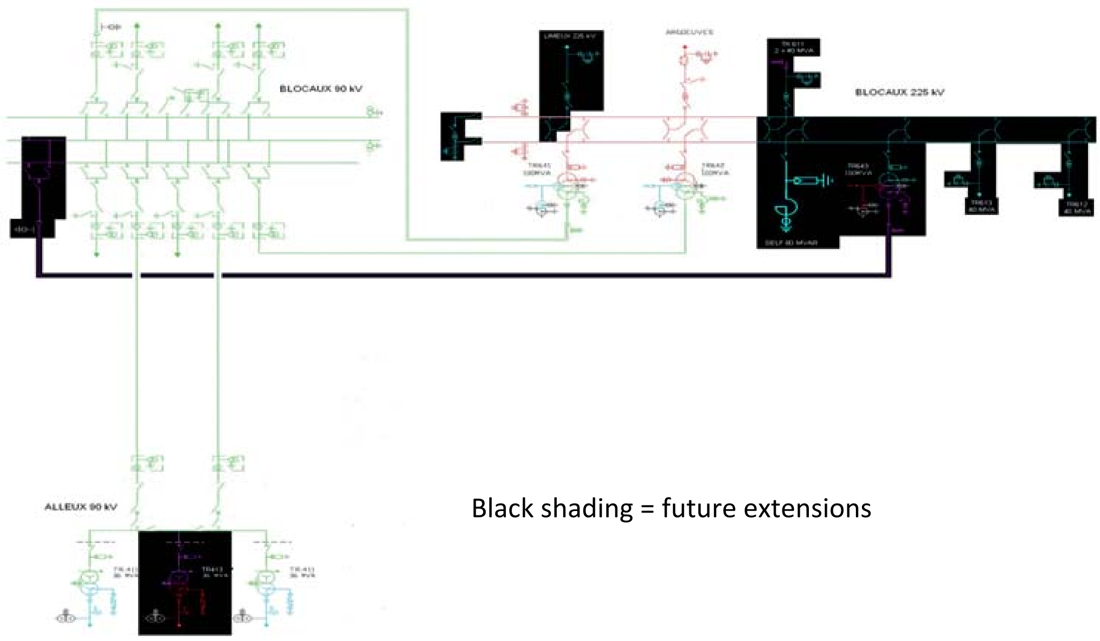


Figure 24: Existing equipment to be upgraded and future extensions.

Partnership Collaboration

The stimulus for this project was an invitation for projects issued by the French environmental and energy agency (ADEME). The project is partially funded by the French government.

The TSO (RTE) and DSO (ERDF) provided the assets and knowledge necessary for conducting a full-size test. They also contribute to the research by making their know-how in design, operation, and maintenance accessible to other participants. Alcatel-Lucent, a major actor in telecommunications, brings its know-how in communication systems and cyber security.

The nature of the partnership allows the different parties to benefit from each other's skills. RTE and ERDF are able to study the functional and economic improvement of the fully digitalised components and measure the benefits of these technologies in an operating system.

Alstom Grid, Schneider Electric, and Neelogy have access to RTE's and ERDF's know-how and assets, and will be able to experiment on full-scale demonstrators. Some research players will act as subcontractors.

Current Status and Results

The Smart Substation project, with its new functionalities, appears to be the first such effort to develop such advanced functionalities. Some of the most important functions include the following:

- Numerical system automation with a new approach of redundancy and reliability
- Several monitoring solutions
- Automatic fault analysis and fault location
- A large-scale weather DLR (380 km of OHL)
- Asset management tools in the substation
- Full remote control
- Extremely compact solutions: numerical system for 22 feeders, 2 voltage levels, and auxiliary supply with batteries for 4 hours autonomy in a single container

Fully compliant with the national framework of industry development as defined by ADEME and various ministries' roadmaps, this project represents a necessary part of the development of smart grids on a European scale, in addition to the other actions undertaken in this field.

Specifications are complete and development is underway, especially in the Alstom Grid Labs. The first results on site will come in 2016.

Lessons Learned and Best Practices

This first year has shown the feasibility of a global process bus, of a complete redundant architecture, and the concept of a wide-area automation solution, which could eventually lead to automatic restoration plans without human actions.

The project demonstrated the feasibility of a sensorless DLR on flat land, though the relevance for a larger area and for lightly wooded land has not yet been verified.

Finally, this first year has shown the relevance of incorporating phase specification nested with the phase of development of the manufacturer. This allows the manufacturer to express its constraints and limitations. Global optimisation clients and subcontractors are sought. RTE and Alstom Grid are both enjoying significant success, and the time savings seen to date is substantial.

Next Steps

The massive implementation process of the decentralised productions, the load shedding on peak hours, and the digitalisation of the grids components will significantly complicate the electrical system, local grid code, and the operating and maintenance conditions. The “centralised” model will not be the technological and economic optimum; an artificial intelligence with distributed advanced automation system algorithms in a spatial scale still undefined will have to be set up.

That technological development (i.e., digitalisation of the components and distributed advanced automation) is in progress in Europe, and specifically in France concerning the TSO (RTE) and DSO (ERDF), as well as manufacturers (Alstom Grid and Schneider Electric).

Digitalisation—and thus automation—of the grids is a major industrial challenge for the coming decades for developed countries' grids, as well as for emerging countries, such as Brazil, China, and India.

SUMMARY: DEVELOPING NEW FUNCTIONS WITH THE SMART SUBSTATION

What is the project about?

The Smart Substation project aims at developing new, digitalised functionalities of the electrical substation, focusing on the ultra-high-voltage grid while considering the interface with the distribution grid. This is an industrial pilot project with experimentation of a new technological package including new advanced control functionalities in the French electrical grid.

The demonstrations will be set in the north of France, where there is significant wind power and where several new parks are planned. Two types of substations will be developed and tested: a transmission substation and a distribution substation that represent the interface between the transmission system and the distribution system. The innovative digitalised architecture will be deployed on existing substations.

Main goals

The Smart Substation project aims to design, build, test, and operate two fully digital smart substations by 2015 in the northern area of France. The project will assess the benefits provided by these solutions, such as a lower environmental impact, better integration of the renewable energy sources (RES), improved transmission capacities, and optimal use of the existing assets.

Current status/timeline

This is a four-year project that began in 2013. Three years will be dedicated to development and one to experimentation. Currently (as of July 2014), specifications are finished and development is underway. The first results on site will come in 2016.

What is the result/expected benefits of the project?

The development of smart substations will enable the electrical power equipment to work closer to their physical limits. At a national scale, a transmission system using smart substations carries more energy than a traditional grid. The development of digitalisation will, also looking at a national scale, enable optimisation of the grid's reinforcement works. The digitisation of all substations is also a technological solution that will contribute to reaching the European commitment to increase RES integration.

What is next?

The project will continue to 2017, with the first results coming from the site in 2016. The project results will be examined and the new functionalities will be further developed. The project results will be investigated based on experiment feedback on the advantages (from the operator's point of view) resulting from digital technologies and advanced functions.

If the outcome is positive, the project will enable the transmission system operator to start drawing up methodologies for the implementation process on site, work on the graphical user interface (which should assist the operators on smart substations management), and prepare for the crafts evolution.

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AUSTRIA

Maximising the DER hosting capacity of low- and medium-voltage networks

Photo: Stockphoto

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Market Structure

One transmission (Austrian Power Grid [APG]) and several distribution companies (all regulated)
Fully deregulated retail electricity market

Electricity Consumed (2013)

69,613 GWh

Peak Demand (2013)

10,092 MW

System Type

Austria is part of the ENTSO-E synchronous power system

Electricity Fuel Mix (2013)

	Production	Ratio
Hydro Power	40,963 GWh	60.5%
Thermal Power[1]	16,489 GWh	24.3%
Wind	2,237 GWh	3.3%
Others (incl. PV)	8,027 GWh	11.8%
Total	67,716 GWh	100%

Installed Power (2012)

23,164 MW

Electricity System (2012) & Interconnection

Total system length is 253,151 km

Voltage level	Overhead [km]	Cable [km]	Total [km]
380 kV	2,783 (1.1%)	55 (0.0 %)	2,838
220 kV	3,662 (1.4%)	5 km (0.0 %)	3,667
110 kV	10,501 (4.1%)	660 (0.3%)	11,161
1kV < 110 kV	28,755 (11.4%)	39,319 (15.5%)	68,074
< 1 kV	37,088 (14.7%)	130,325 (51.5%)	167,412
Total	82,788 (32.7%)	170,363 (67.3%)	253,151

(Source e-control Austria)
There are several links to the neighbouring countries: Germany, Czech Republic, Hungary, Slovenia, Italy, and Switzerland.

Contact

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[1] Coal 6,097 GWh, Oil 683 GWh, Gas 6,416 GWh, and Others (biomass and waste) 3,293 GWh

AUSTRIA

Maximising the DER hosting capacity of low- and medium-voltage networks

CASE

Project name:	**Maximising the DER hosting capacity of low- and medium-voltage networks**
Leading organization:	**AIT**
Commissioning year:	**2014**
Type of project:	**Field test pilot**

CASE HIGHLIGHTS

The hosting capacity can be increased in low- and medium-voltage networks through smart planning, smart monitoring, and smart control.

Different control possibilities for voltage band management in medium-voltage networks with high share of distributed generation ***were proven successful:***

- A stand-alone solution integrated at substation level based on measurements
- A distributed management system based on state estimation both controlling setpoints of the on-load tap-changer transformer and generators

With Intelligent planning of DG integration supported by monitoring, the hosting capacity of LV networks can be significantly increased. In term of active network control a distributed control approach seems to be the most successful.

[2] The Demo Case Austria is presenting different projects: DG DemoNet- Concept & Validation, ZUQDE, ISOLVES: PSSA-M and DG DemoNet Smart LV Grid

Introduction

In Austria, approximately 60% of the electricity is produced by hydropower. There is a significant share of large hydropower plants (e.g., along the river Danube) and pump storages (located in the Alps region), as well as small- and medium-scale hydro plants in the mountains. Hence, the share of renewable-based electricity generation in Austria is already very high. Nevertheless, it is expected that additional renewables—mainly wind, small hydro, and photovoltaics (PV)—are going to be integrated, primarily in distribution networks.

Austrian distribution grids are operated by approximately 140 distribution network operators (including a large number of municipal utilities and small local network operators). The distribution network is typically designed with three voltage levels:

- High voltage (HV): 110 kV
- Medium voltage (MV): 10 kV (mainly urban) to 30 kV
- Low voltage (LV): 0.4 kV

The primary driver for Demo Case Austria is the massive integration of renewable-based distributed generation (DG) into the distribution system, primarily in rural areas. The projects presented here seek to increase the hosting capacity of the existing MV and LV distribution networks for distributed energy resources (DER), including DG, demand response (DR), and electric vehicles.

Objectives and Benefits

The main objective of Demo Case Austria is to find an efficient way to integrate renewable-based DG with regard to optimised investment by maximising the utilisation of the existing asset base in MV and LV grids. The main challenge of integrating DER in distribution networks is keeping the voltage within the specified limits (voltage band, in compliance with EN 50160 “Voltage characteristics of electricity supplied by public distribution systems”). Thus, the main functions elaborated in the field tests are the following:

- Smart planning
- Smart monitoring
- Smart control

AUSTRIA

Maximising the DER hosting capacity of low- and medium-voltage networks

The following activities for increasing DER hosting capacity in MV and LV distribution networks are included in this case study:

- Increasing DER hosting capacity in MV networks and related voltage control concepts

  > Network operators: Vorarlberger Energienetze GmbH, Salzburg Netz GmbH

  > Field tests and demonstrations in Großes Walsertal and Lungau

  > Specific related projects: DG DemoNet Concept & Validation, ZUQDE

- Increasing DER hosting capacity in LV networks and related voltage control concepts

  > Network Operators: Salzburg Netz GmbH, Netz Oberösterreich GmbH,

  Linz Stromnetz GmbH

  > Field tests and demonstrations in Köstendorf, Eberstalzell, and Prendt

  > Specific related projects: ISOLVES: PSSA-M and DG DemoNet Smart LV Grid

The expected impact and validated impact of the controls and solutions developed and demonstrated are as follows:

Enhancement of renewable energy sources integration:
Hosting capacity can be significantly increased by implementing voltage control concepts in MV networks (e.g., the ZUQDE system enables a further increase of DG generation capacity by 20% in the critical network section). It is expected that, compared to conventional approaches, the intelligent planning, intelligent monitoring, and active management and control approaches tested in the project can double the hosting capacity of given LV networks for distributed PV systems.

Losses reduction:
The minimisation of distribution losses is one of the functions of the ZUQDE control system. It is, however, hard to quantify and depends on the target function selected for the optimal power flow algorithm. In LV networks, a maximum utilisation of on-site generated energy results in reduced power flows and thereby reduces losses compared to business as usual. However, compared to the reference scenario grid reinforcement, the overall distribution losses might be higher.

Greenhouse gas (GHG) emissions reduction:
GHG emissions are reduced as a result of the increased hosting capacity and consequent increased generation of more renewable energy. An additional generation capacity of 1.7 MW of small hydropower in the MV region of Lungau results in approximately 8.5 MWh of renewable energy. Compared to thermal power plants using fuel oil, this results in the reduction of carbon dioxide emissions by 5.5 tonnes per year. The same assessments are going to be done in the course of the LV network field tests. A rough estimation results in a reduction of 160 tonnes of carbon dioxide emissions through the demo project.

Integration between producers, consumers, and prosumers:

In order to increase the flexibility to control reactive and active power flow in the LV demo sites, consumers are going to be considered as actively integrated prosumers in an LV smart grid operation. It is also possible to integrate consumers (loads) into the control approaches at the MV level. This was, however, not implemented in the demo project.

Synergies with smart metering systems:

In the LV network, a smart metering system improves network monitoring within the network control approach and also improves the energy usage and generation information available to consumers.

Future deployment of advanced services:

All smart grid applications developed and tested by the individual projects are part of an overall smart grid approach to enable advanced services.

Technology

Demo case MV network

In principle, two different approaches are used in the MV demo case. The DG DemoNet approach is a stand-alone solution integrated at substation level based on measurements in the grid,[3] and the ZUQDE approach is a solution integrated in a distribution management system (DMS) based on state estimation.

DG DemoNet approach

A central voltage control unit located at the primary substation uses voltage measurement at "critical nodes" (identified through offline studies) for dynamic control of the on-load tap-changer (OLTC) transformer and hierarchical control of generators (reactive power [volt/var] control of hydropower plants). The main function is voltage band management (fulfilment of the required voltage limits) in order to increase the DER hosting capacity of the existing MV network infrastructure.

The main functions are the following:

- Voltage band management (fulfilment of the desired voltage limits)
- Reactive power management

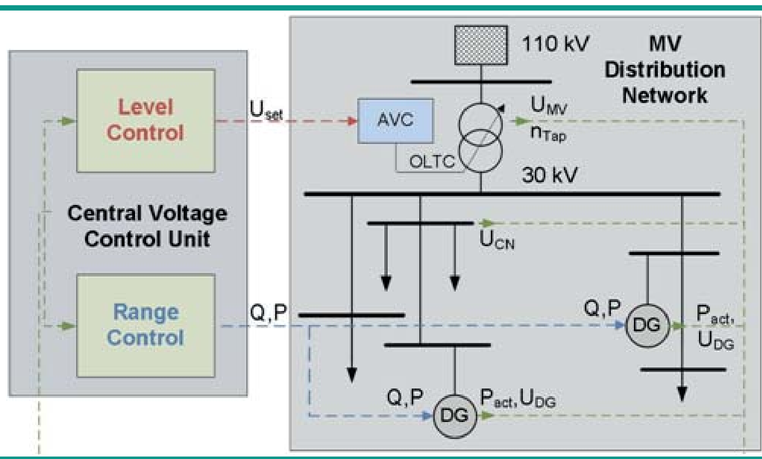

Figure 25: DG DemoNet voltage controller architecture.

[3] R. Schwalbe, W. Prüggler, H. Brunner, B. Bletterie, A. Abart, R. Pointner, F. Herb: *"DG DEMONET - Final Results Of Field Trial Validation Of Coordinated Volt/Var Control*"; CIRED Workshop 2014, Rome, Italy 11th June 2014 – 12th June 2014

ZUQDE approach

The ZUGDE controller aims at a central optimisation of the set points for the OLTC transformer and the generators (reactive power) via applications in the DMS. A distribution system state estimator (DSSE) uses a network model and the primary voltage of the 110/30 kV transformer for an optimised online calculation of the network situation. Based on the state estimation and the selected target function, the Voltage/VAR Controller (VVC) defines the set points.

There are three main functions:

- Voltage band management (fulfilment of the required voltage limits)
- Minimisation of network losses
- Reactive power management

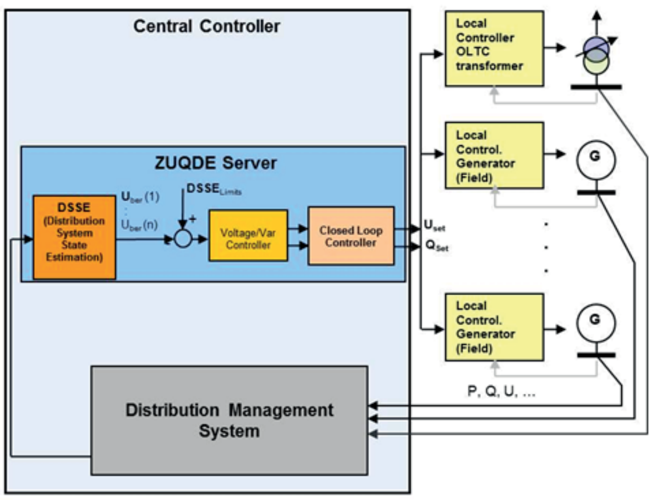

Figure 26: ZUQDE controller architecture.

Demo case LV networks

For LV networks, three different use cases have been designed:

- ***Prendt*** (intelligent planning and smart monitoring): Verification of the **probabilistic planning** method by measurements in a grid with a **high penetration of PV**.
- ***Eberstalzell*** (smart sensing and coordinated generation control): Testing of the control and monitoring solutions in a grid with a **high penetration of PV** based on smart metering communication infrastructure.
- ***Köstendorf*** (smart sensoring and coordinated load control): Testing of the control and monitoring solutions in a grid with a **high penetration of PV** linked with a **high penetration of electric vehicles**.

The demonstration networks developed and implemented different approaches for voltage control in LV networks with a high share of PV and electric vehicles:

1. The OLTC in the secondary substation, as well as the other components within the test area, use their integrated controls and characteristics without communicating with each other (local control).
2. The OLTC receives measurement data from preselected points in the grid so that it can change the tap position to an ideal level for the whole grid (distributed control).
3. In addition to approach 2, all distributed devices (e.g., PV inverters and electric vehicle charging stations) receive the same set points and characteristics (e.g., depending on reactive power control and voltage electric vehicle charging), which are optimised for the current status of the grid (coordinated control).
4. In contrast to approach 3, each device receives its own characteristics.
5. To maximise the effect, devices near the transformer station and devices far from the station are handled differently.

The algorithms for the coordinated control are located in the so-called Low Voltage Grid Controller (LVGC) at the secondary substation level. A communication technology broadband connection via internet protocol (IP), as well as via programmable logic controller (PLC), is used. Smart meters act as monitoring devices for the entire control system. Special gateways to PV inverters and charging stations have been developed within the project.

Community Engagement

In the MV network projects, the involvement of the community is limited to the operators of the DG units, who agreed to join the demonstration project and participate via reactive power control. Because of the possible loss of income, the active power curtailment was not used in the demonstration phase.

In the LV-level projects, there was high community engagement. In the preparation phase of the project, LV demonstration networks were chosen according to the technical suitability of the networks, as well as the willingness of the local people to be part of the project. Supported by a special funding scheme in all LV networks, 50% of the inhabitants decided to invest in a PV rooftop installation (e.g., 43 in Köstendorf and 75 in Eberstalzell). In Köstendorf, people had the possibility to get an electric vehicle for the duration of the demonstration phase (36 electric vehicles are now in operation) in addition to the PV installation in which they invested. Within a couple of days, all of the available PV installations and electric vehicles had been allocated.

Current Status and Results

Demo case MV network

The solutions that were realised with the ZUQDE approach and demonstrated in the field test area Lungau, including the integration in the grid control platform, have been successfully demonstrated from a technical, operational, and economic perspective. The developed software package, including DSSE and VVC, fulfilled the defined functionalities for supporting network operation in terms of voltage band management with a high share of DG. In principle, the cascaded control can be implemented in all MV networks covered by the existing grid control platform.

The solutions realised with the DG DemoNet approach confirmed the feasibility and the success of the concept, and also showed that conventional alternatives to grid reinforcement like "ring" switching state and optimally configured line drop compensation can be cost efficient.

Even if the gain in voltage band usage in the field test was slightly smaller than expected according to the simulations in the two demonstration grids (due to deficiencies in the load models), the principal functioning of the developed control concepts was validated in the course of the one-year field test phase. During the validation of this project, no significant DG capacities (e.g., of up to 17 MW in demo case Großes Walsertal) were installed in the demonstration grids, so the total potential of the control concepts still relies on simulation results of former work. However, the control functions still can be expected to become a powerful and flexible tool for distribution systems operators (DSOs) to economically integrate extra DG in recently reinforced grids.

Even if the related project was officially finished at the end of 2013, the DG DemoNet controllers are still in operation in the network area of Großes Walsertal.

Demo case LV networks

Simulations show that some of the described control stages are of limited suitability in the considered LV grids because of the complexity of LV grids. Under unsymmetrical conditions, strong feeder diversity and a strongly non-uniform load/generation distribution line drop compensation is not suitable for estimating voltage conditions in the examined grids. Because of the network specificities (strong MV-connection) and the properties of the transformer prototype (large tap size), the benefits of the local transformer bus bar voltage control (Approach 1) are very limited. Nevertheless, in LV grids connected to a highly variable MV grid and with transformers exhibiting a smaller tap size, this simple control concept (Approach 1) can enhance the network operation and increase the hosting capacity. By decoupling the MV from the LV, some reserves can be relieved and made available for the connection of additional network users (PV generators or charging stations for electric vehicles).

The simulations performed for the distributed voltage control (Approach 2) led to promising simulation results, showing that the node voltages can be safely kept within the given limits.

For the more complex control stages (Approach 3–5) the additional advantage in terms of voltage band utilisation in the three field test areas is limited, because of the specifics of the investigated grids. Compared to the increasing complexity and additional requirements on the system architecture, the benefit for the voltage band management is quite limited.

The control concepts developed and tested within a simulation environment were validated in three Austrian LV grids until the end of 2014. The results and experiences will be published. Initial experiences showed that, with intelligent planning of DG integration supported by better knowledge of the network through monitoring, the hosting capacity of LV networks can be significantly increased compared to conventional network planning.

Lessons Learned and Best Practices

ZUQDE approach (MV): The grid control platform (DMS) requires related data (e.g., load models) and the remote control of DG and the OLTC transformer in the substation (telecontrol). The higher requirement for data availability is caused by the state estimation.

The operation of a network with a cascaded control is going to be more complex, because of the interaction of a higher number of stakeholders and the reliability requirements followed by less reserve in the network. The failure of an individual component will influence the entire system. The system needs to be designed in such a way that with the loss of one component, the network can still operate. This was tested by chance in the demonstration phase, when the telecontrol system failed. The system went into a local operation mode (for each individual component), and the network was still operated within the limits.

The following questions need to be answered when there is a very high number of DG and the operational limits of the network are exhausted by “smart grid controls”:

- What is the maximum number of DG units at which the fall-back into a local control is no longer suitable?
- What would be suitable measures to counteract a situation in which local control is no longer suitable (e.g., switching of loads or generators, active power curtailment)?

DG DemoNet approach: The three main challenges concerning the realisation of coordinated voltage control in the expected grids were the following:

- Installation of the distributed measurement devices with telecontrol connection
- Integration of existing DG into the control process
- Topology recognition and the integration of the controller into the existing process control system

As the permanent observation of the voltage situation at selected grid nodes gets more and more important to ensure voltage quality at customer connection points, costs for necessary measurement devices can be shared among different use cases, resulting in even higher cost advantages for DSOs and DG units.

LV networks: Specific characteristics of the networks have a strong impact on the benefits that could be gained from the different approaches for voltage control.

Next Steps

The demonstrations and the evaluation of related field tests for LV networks were completed at the end of 2014. A follow-up project to investigate the integration of small-scale storage in the field test areas is under preparation.

The ZUQDE approach is already commercialised and available as a module within a grid control platform (Siemens Grid Control Platform Spectrum). Addressing the challenge of topology recognition for the DG DemoNet approach, an enhancement of the algorithms towards adaptive control is under preparation in order to avoid the necessity of knowing the network topology.

One important issue for further investigation is the replicability and scalability of the developed solution—in Austria as well as in Europe—in order to identify networks where similar problems may occur and test whether these solutions will be suitable. The above-presented demo cases and their respective DSOs (Salzburg Netz Gmbh and Netz Oberösterreich GmbH), as well as the Austrian Institute of Technology, are partners within the European FP7 Project iGREENGrid (which started in early 2013), which focuses on investigating replicability and scalability of the specific solutions by establishing a family of relevant national projects (six European key demonstration projects) focused on the effective integration of variable DG in power distribution grids.

Additionally, based on the experiences in LV and MV networks, the next step will be to investigate, further develop, and demonstrate the interaction of all the controls in HV, MV, and LV levels and include them in the operational network management.

SUMMARY: MAXIMISING THE DER HOSTING CAPACITY OF LOW- AND MEDIUM-VOLTAGE NETWORKS

What is the project about?

The main challenge of integrating distributed energy resources (DER) in rural distribution networks is keeping the voltage within the specified limits (i.e., in compliance with EN 50160). This study considers how to maximise the hosting capacity of DER in low-voltage (LV) and medium-voltage (MV) networks through the use of smart planning, smart monitoring, and smart control.

Main goals

The main goal of the project is to find an efficient way for the integration of renewable-based distributed generation (DG) with regard to optimised investment by maximising the utilisation of the existing asset base in LV and MV grids. The focus of the related projects presented in this case study is to increase the hosting capacity of LV and MV distribution networks for distributed energy resources, including DG, demand response, and electric vehicles.

Current status/timeline

The demonstrations and the evaluation of related field tests for LV networks were finalised at the end of 2014. Currently, a follow-up project on the integration of small-scale storage in the field test area is under preparation. One of the solutions for MV networks is already commercialised, and for the other solution, an enhancement of the algorithms is under preparation.

What is the result/expected benefits of the project?

Implementation of voltage control concepts in LV and MV networks can increase the hosting capacity significantly. Examples of other benefits include the possibility of lower losses and reduced greenhouse gas emissions.

All smart grid applications developed and tested within the individual projects are seen as part of an overall smart grid approach, which should enable advanced services.

What is next?

One important issue is to further investigate the replicability and scalability of the developed solution in Austria. Therefore, networks where similar problems may occur should be identified and used to determine whether these solutions will be suitable. Additionally, based on the experiences in LV and MV networks, the next step will be to investigate, further develop, and demonstrate the interaction of all the controls in high voltage, MV, and LV levels and include them in the operational network management.

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ITALY

Impact of the enforcement of a time-of-use tariff on residential customers in Italy

ITALY	
Market Structure	The publicly listed company Terna owns and operates most of the transmission grid in Italy under a natural monopoly; the distribution grid is managed by DSOs under a state concession regime.
Electricity Consumed (2013)	297,000 GWh
Peak Demand (2013)	53,942 MW
System Type	Synchronous European Grid (34 European countries connected)
Electricity Fuel Mix (2013)	Thermal 72.4% Hydro 17.8% Other RES 9.8%
Installed Power (2013)	125,000 MW (net), 129,000 MW (gross)
Interconnection	Italy is interconnected to France, Switzerland, Austria, Slovenia, and Greece; a new high-voltage direct current interconnection is planned between Italy and Montenegro.
Contact	Simone Maggiore RSE S.p.A. - Ricerca sul Sistema Energetico simone.maggiore@rse-web.it

This case is a shortened version of the full report (with original sources), available at http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6683276&tag=1

ITALY

Impact of the enforcement of a time-of-use tariff on residential customers in Italy

CASE

Project name:	**Introduction of ToU tariff**
Leading organization:	**Italian AEEG[1]**
Tariff introduction:	**2011**
Type of project:	**Commercial**

CASE HIGHLIGHTS

Time-of-Use (ToU) tariffs reduce the complexity of the metering infrastructure and extend the time slots, leading to incentives for customer to adjust their consumption during peak hours. At the same time, ToU tariffs protect those who are not able to modulate their demand.

Benefits of ToU tariffs include the following:

- ***Improve the efficiency*** of the whole Italian T&D system
- ***Illustrate for customers their role*** in shaping their energy consumption

[1] Authority for Electricity and Gas

Introduction

The Italian Authority for Electricity and Gas (AEEG) approved the implementation of a mandatory Time-of-Use (ToU) tariff based on two time slots for residential customers in Italy, starting July 1, 2010. The introduction of the ToU tariff is the final step of a process that was designed to progressively expose Italian customers to time-variable costs of electricity supply. The process started several years ago with high- and medium-voltage customers, and was extended to low voltage.

The mandatory ToU tariff provides variable prices of electricity depending on the hour of the day. Prices are higher during "peak hours" (between 08:00 and 19:00 hours during working days) and lower during "off-peak hours" (which comprise the remaining hours). The energy prices during peak and off-peak hours are, respectively, higher and lower than the corresponding value of a hypothetical flat tariff; however, the differences between the flat and the ToU tariff prices are higher at peak time than at off-peak, due to the fact that off-peak hours occur more than twice as often as peak hours during a typical year. The values of energy price differences relative to the third quarter of 2011 are shown in the following table:

Energy price difference between flat and ToU tariff during the transition period	
Peak hours	-0.592 c€/kWh
Off-peak hours	0.297 c€/kWh

Table: Price difference between flat and ToU tariff[2] (VAT excluded[3]).

The price difference between peak and off-peak hours (equal to 0.889 c€/kWh, value-added tax [VAT] excluded) corresponds to 10% of the energy price during peak hours; however, the other components of the tariff, which do not depend on the time of day, make the final price variation between peak and off-peak hours much lower than the aforementioned 10%. The percentage decreases as the annual consumption of the customer increases (from 7% for the lowest range of consumption to about 4% for the highest range).

The convenience of the ToU tariff with respect to the flat tariff depends on the distribution of customer consumption between peak and off-peak hours. If more than two-thirds of the consumption is during off-peak hours (i.e., during nights or weekends), the ToU tariff is less expensive than the flat tariff. Otherwise there is a cost increase. Two-thirds of the total consumption (66.67%) is called the indifference threshold.

It should be noted that the price difference of the Italian ToU tariff is extremely low in comparison to similar tariffs adopted in other countries.

[2] Deliberation ARG/elt 30/11, available at http://www.autorita.energia.it/allegati/docs/11/030-11argalla.xls
[3] VAT is 10% for residential customers.

ITALY

Impact of the enforcement of a time-of-use tariff on residential customers in Italy

Objectives and Benefits

The main goal of the ToU tariff program is to improve the efficiency of the whole Italian system by encouraging customers to reduce their consumption during high-demand hours. This will lead to a decreased need to reinforce the network to handle high power flows during peak hours.

Flat rate is the most common method to bill electricity consumption because it minimises the costs of metering and billing. However, it does not induce customers to adjust their consumption according to the abundance or scarcity of electricity. In particular, it does not encourage them to lower it during high demand hours.

Conversely, real-time rates link the price paid by the customers to the real costs of electricity. This method requires a more complex metering infrastructure because consumption needs to be recorded for each time interval with the specific price, but it allows price signals to reach the customers in the proper way. The drawback is the fact that customers who are unable to move their electricity consumption will face higher costs.

ToU tariffs serve as a middle ground. There are a certain number of time slots during the day in which the price paid by the customers is established in advance, based on mid-term (e.g., quarterly) predictions. This allows for a less complex metering infrastructure, and, the longer the time slots, the more averaged/smooth the price signals are. Such a mechanism relates, to a degree, the price variability of electricity with the costs of its supply, allowing a collaborative response to the customers' energy demands (the demand response). At the same time, it relatively protects (with regard to real time rates) those who are not able to modulate their demand according to the price.

Project and Technology Description

The introduction of the ToU tariff for residential customers in Italy is a significant event. In fact, 20 million families are currently paying their electricity consumptions based on a variable price during the day. This situation represents an unprecedented occasion to analyse the changes in customers' behaviour in response to time-variable electricity prices.

In order to assess the impact of the ToU tariff in the short and medium terms on the Italian consumers, RSE started a research project in collaboration with and under the patronage of AEEG.

To this aim, a group of approximately 28,000 households (the customer panel) was selected to statistically represent the whole Italian population. Their monthly electricity consumption data, as measured by smart meters, was collected starting in July 2009 (i.e., one year before the introduction of the mandatory ToU tariff). This study allowed for an analysis of the change of consumption behaviour after the introduction of the transitional ToU tariff.

To improve the significance of the analysis, a restricted customer panel was selected based on several requirements,[4] and a comparison was made between the customers' behaviour in two different semesters that were one year apart:

- Flat rate period: January 1, 2010–June 30, 2010
- ToU rate period: January 1, 2011–June 30, 2011

The restricted customer panel includes 9,952 customers (i.e., about one-third of the overall customer panel). Comparisons of the two panels showed that the restricted customer panel had a composition statistically in line with that of the customer panel, as well as of the Italian population.

Community and Workforce Engagement

The ToU tariff represented a strong innovation for Italian residential customers. Hence, AEEG decided that it should be introduced gradually: An 18-month transition period was scheduled from July 1, 2010 to December 31, 2011, with a limited price difference between peak and off-peak hours (a transitional ToU tariff). After that period, the price difference became larger, in accordance with the competitive market price of electricity (the final ToU tariff). In order to make customers aware, the AEEG planned an informative campaign on mass media prior to the introduction of the ToU tariff.

Current Status and Results

The monthly average percentage of consumption allocated during off-peak hours was about 66.95% in the period with a flat rate tariff (i.e., slightly above the indifference threshold[5] of 66.67%), even in the absence of any price signal provided by the tariff. This corresponded to about 55% of the customers in the "restricted customer panel." This group would have saved money if they had been billed with the ToU tariff in the period with flat rate.

[4] They had no electricity generation systems (for example PV panels); they belonged to the "franchise market" (i.e., customers who have not signed a contract with an energy supplier operating on the liberalised electricity market and, therefore, are subject to the regulated tariffs defined by AEEG); and they had no variations in the contract (e.g., maximum power supplied).

[5] The least amount of the total consumption allocated during off-peak hours that allowed the customer to save money with the ToU tariff with respect to the flat tariff.

Figure 27 shows the variation of the percentage of the monthly average consumption allocation during peak and off-peak hours from the period with a flat rate to the period with the ToU tariff. As can be seen, there had been a slight shift in consumption towards off-peak hours in all months (a monthly average consumption shift of 0.83% towards off-peak hours).

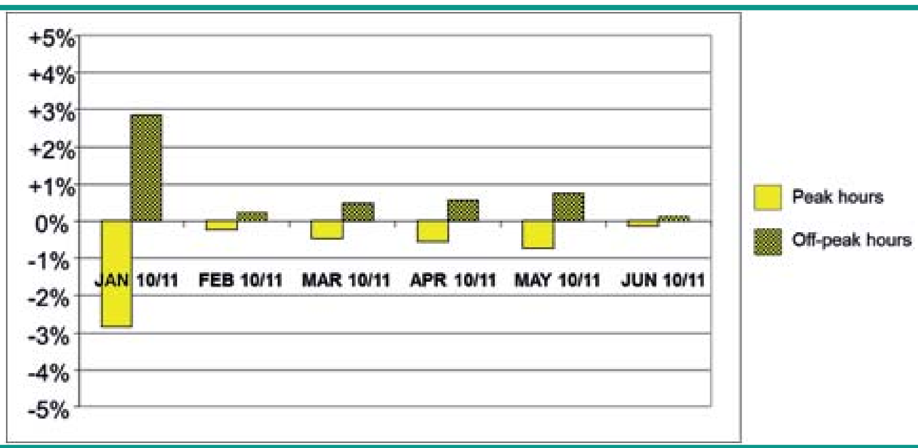

Figure 27: Variation of consumption allocation between peak and off-peak hours for the consumers belonging to the "restricted customer panel."

The percentage of consumers belonging to the restricted customer panel whose consumption is concentrated in off-peak hours (above the indifference threshold) in the period with the ToU tariff is about 59%, an increase of about 4% with respect to the corresponding percentage found in the period with a flat rate. This group had a small average monthly saving equal to about 0.8 c€/month for each customer. During this period, 61.5% of the customers shifted their average monthly consumption towards off-peak hours. Therefore, most residential customers demonstrated a willingness to modify their habits by adjusting their consumption according to the price signal provided by the ToU tariff. The average shift in consumption for each customer was approximately 0.96 kWh/month.

It is important to keep in mind that the variation of the expense is the result of two different effects for each customer:

- The customer's original consumption allocation between peak and off-peak hours before the application of the ToU tariff (in the period with a flat rate) can, by itself, make the ToU tariff convenient or not.
- The application of the ToU tariff (in the period with the ToU tariff) can have induced the customer to shift his/her consumption from peak to off-peak hours, in accordance with the price signal.

The combination of both the above factors can determine a cost increase or decrease for the customer, with respect to what he/she would have paid with a hypothetical flat tariff in the second period (with the ToU tariff).

The resulting average monthly savings of less than 1 c€ might seem quite low at a first glance, but it must be compared with the maximum achievable monthly savings of a customer hypothetically capable of concentrating all his/her consumption during off-peak hours: in such a case, the savings would be equal to about 29 c€/month.[6] Of course, such a case is unattainable; a more realistic scenario would be achieving a consumption allocation during off-peak hours of 70%, which would yield average savings around 2.8 c€/month.

It should be emphasised that the moderate savings are also due to the low price difference between peak and off-peak hours.

Customer behaviour following the ToU tariff was mixed and not classifiable in a single category. There are, in fact, customers who responded consistently to the price signal given by the ToU tariff and customers who did not. However, more customers shifted their consumption from peak to off-peak hours than shifted their consumption in the opposite direction; moreover, the customers who started from a disadvantaged position were more responsive to the price signal given by the ToU tariff than the other customers.

In Figure 28, each customer is identified by a single coloured dot according to his/her consumption allocation between peak and off-peak hours in the period with a flat rate: green dots for customers with consumption concentrated in off-peak hours and red dots for the others. The y-axis represents the average monthly consumption shift from peak to off-peak hours in the period with the ToU tariff, while the x-axis represents the average monthly savings in the period with the ToU tariff.

Figure 28 can be further divided into six different sectors, each defining a specific customer behaviour as a consequence of the introduction of the ToU tariff:

- **A (further improvement):** Customers whose consumption was initially concentrated in off-peak hours, who initially benefited from the ToU tariff and who amplified their savings by further shifting their consumption towards off-peak hours (about 29.2% of the total).

- **B (improvement with success):** Customers whose consumption was initially concentrated in peak hours, and who shifted their consumption towards off-peak hours. This shift let them save money with the ToU billing with respect to the hypothetical billing of the same consumption with a flat tariff (about 12.4% of the total).

[6] For an average annual consumption of 2,180 kWh.

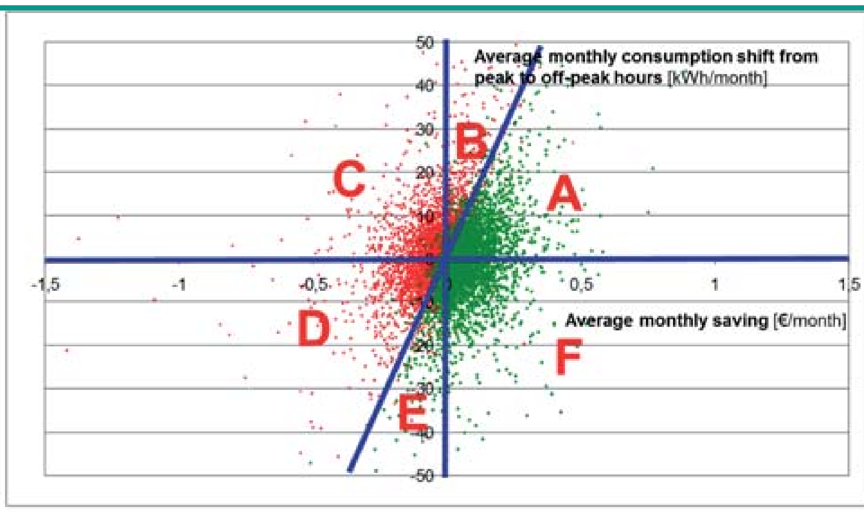

Figure 28: Customers' classifications according to their behaviour in the period with the ToU tariff as a consequence of the introduction of the ToU tariff.

- **C (Gradual improvement):** Customers whose consumption was initially concentrated in peak hours, and who shifted their consumption towards off-peak hours; nevertheless, the shifted amount was not enough to let them save money with the ToU billing with respect to the hypothetical billing of the same consumption with a flat tariff (about 19.8% of the total).

- **D (Further worsening):** Customers whose consumption was initially concentrated in peak hours, and who further shifted their consumption towards peak hours. This shift made their bill increase due to the application of the ToU tariff (about 11.9% of the total).

- **E (Drastic worsening):** Customers whose consumption was initially concentrated in off-peak hours, and who shifted their consumption towards peak hours so as to exceed the indifference threshold. This shift produced a cost increase in their billing with the ToU tariff with respect to the hypothetical billing of the same consumption with a flat tariff (about 8.5% of the total).

- **F (Gradual worsening):** Customers whose consumption was initially concentrated in off-peak hours and who shifted their consumption towards peak hours, but did not exceed the indifference threshold; their cost savings with the ToU tariff, with respect to the hypothetical billing of the same consumptions with a flat tariff, would have been greater if they had not changed their behaviour (about 18.2% of the total).

The mandatory ToU tariff in Italy has improved the efficiency of the whole Italian T&D system, moving approximately 1% of the residential consumption from peak hours to off-peak hours. In particular, it has demonstrated the role of the customers in shaping their energy consumption as active users in order to face time-dependent electricity costs.

Lessons Learned and Best Practices

The results show that, even if there has been a limited shift of consumption from peak hours to off-peak hours in the period following the introduction of the mandatory ToU tariff, the change in user behaviour is not negligible; the ToU tariff in Italy has been capable of shaping users' habits to a certain extent, according to the price signal.

The limited percentage of the shift detected (about 1%) requires some cautiousness before deriving a definitive conclusion about the causes underlying it. First of all, there are two aspects that might have prevented a larger shift from occurring:

- Consumption allocation during off-peak hours in the residential sector was very close to, and sometimes greater than, the indifference threshold previously defined (two-thirds of the total consumption), even before the introduction of the ToU tariff.
- The price difference between peak and off-peak hours was miniscule, which inevitably conveyed a weak price signal to the customers.

The price difference between peak and off-peak hours decreased in 2013 with respect to 2012 due to several factors, including the growing diffusion of distributed generation in Italy (mainly photovoltaic plants) and the fact that the current subdivision of the day into different time slots, for the sake of simplicity, does not fully reflect the order stemming from the average of electricity market prices in the different hours.

It is also interesting to highlight the large variety of customers' behaviour. Some customers radically changed their behaviour in order to comply with the dictates of the ToU tariff, while other customers moved their consumption in the opposite direction. Moreover, it is clear that the ToU tariff has caused a cost increase for some customers, but it is not clear if and to what extent these customers are aware of the increase itself.

In order to maximise the effectiveness of the ToU tariff, it is advisable to systematically provide, in each bill, a report of the cost savings or increase achieved by the customer with the ToU tariff in comparison to a hypothetical flat tariff. There are several aspects that should be improved to make the tariff more effective: the allocation of the hours between peak and off-peak should be revised, a new group of hours intermediate between peak and off-peak ones should be introduced, and the price signal should be increased. These changes will give more flexibility to users and will encourage them to shift their consumption to time slots where the price is lower.

Next Steps

The analysis has continued with the goal of determining if the consumption shift trend persists. The response capability of consumers, in fact, should increase in the long term as customers have time to adapt to persistent price signals by consolidating their consumption habits and making investments to improve their domestic energy use (e.g., purchasing intelligent home appliances that can be programmed by the user).

Another approach that may be used in the Italian market in combination with the ToU tariff is critical peak pricing (CPP), which consists of a significant increase in the electricity price during short-duration periods when the reserve margin is low. The higher price difference and the shorter duration of time intervals are the two factors that allow a significant load shift from peak hours to be achieved with respect to ToU tariffs.

However, both the modification of the composition of the time slots and the introduction of the CPP would require some substantial interventions on the measurement system. In the former case, time slots should be reprogrammed in the smart meters, while in the latter case, reprogramming should occur close to real time when a reduction in the reserve margin occurs.

SUMMARY: IMPACT OF THE ENFORCEMENT OF A TIME-OF-USE TARIFF ON RESIDENTIAL CUSTOMERS

What is the project about?

The Italian Authority for Electricity and Gas (AEEG) approved the implementation of a mandatory Time-of-Use tariff (ToU) based on two time slots for residential customers in Italy starting July 1, 2010. The introduction of the ToU tariff is the last step of a process that was designed to progressively expose Italian customers to time-variable costs of electricity supply. The introduction of the ToU tariff for residential customers in Italy is a significant event; currently, 20 million families are paying their electricity consumption with a variable price during the day, which created an unprecedented occasion to analyse the changes of customer behaviours in response to time-variable electricity prices. In order to assess the impact of the ToU tariff on the Italian consumers in the short and medium terms, RSE ran this research project in collaboration with, and under the patronage of, AEEG.

Main goals

The main goal of the project was to evaluate the impact of a ToU tariff on residential customers in Italy. In the long run, the goal is to induce the Italian customers to adjust their consumption according to the abundance or scarcity of electricity, leading to a decreased need to reinforce the network due to high loads during peak hours.

Current status/timeline

The ToU tariff was introduced gradually, with an 18-month transition period (from July 1, 2010, to December 31, 2011) with a limited price difference between peak and off-peak hours (a transitional ToU tariff). After this period, the price difference became larger, in accordance with the competitive market price of electricity (the final ToU tariff).

What is the result/expected benefits of the project?

The results show that, even if there has been a limited shift of consumption from peak hours to off-peak hours in the period following the introduction of the mandatory ToU tariff, the change in the behaviour of the users is not negligible. The ToU tariff in Italy has been capable of shaping users' habits to a certain extent, according to price signal. Also, the mandatory ToU tariff in Italy has contributed to improving the efficiency of the whole Italian system, moving a percentage of the residential consumption from peak hours to off-peak hours. In particular, it has demonstrated the role of the customers in shaping their energy consumption as active users in order to face time-dependent electricity costs.

What is next?

The analysis has continued, with the goal of determining if the consumption shift trend persists or not. Another approach that may be used in combination with the ToU tariff is critical peak pricing, which consists of a significant increase in the electricity price during short duration periods in which the reserve margin is low. The higher price difference and the shorter duration of time intervals are the two factors that allow a significant load shift from peak hours to be achieved with respect to ToU tariffs.

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Related Projects

There are of course many more smart grid related projects that are implemented all over the world than the ones described in this case book.

Further information could for example be found in the SMART GRID PROJECT CATALOGUES published by ISGAN Annex 1. The catalogues are published in two parts. The first part lists the smart grid projects by their specified Project Main Application and the second part lists them by their contribution to policy goal.
Both part can be downloaded from the ISGAN webpage:
http://www.iea-isgan.org/?c=5/112/366&uid=1310

Some related projects are listed on the following pages.

RELATED PROJECTS

HVDC

Statnett and Energinet, Skagerrak 4:

The new link is of the HVDC Light technology and will boost transmission capacity between the mainly hydroelectric-based Norwegian system and the wind and thermal power-based Danish system. It will enable both networks to add more renewable energy to their energy mix, and to use electricity more efficiently. The system will help overcome distance and grid constraints while ensuring robust performance, power quality and minimal electrical losses.

http://new.abb.com/systems/hvdc/references/skagerrak

American Transmission Company (ATC), Mackinac back-to-back:

200 MW back-to-back HVDC Light station. The station will help control power flow enhance grid stability and allow for the integration of additional renewable energy sources in the state of Michigan, U.S. The Mackinac back-to-back HVDC Light installation provides a buffer that can slow down and redirect large amounts of electrical power so the regional network isn't overwhelmed.

http://new.abb.com/systems/hvdc/references/mackinac

WAMS

Entergy Services, Deployment & Integration of Synchro Phasor Technology:

Project is deploying phasor measurement units (PMUs), phasor data concentrators (PDCs), and state of the art decision support tools across Louisiana, Mississippi, Arkansas, and non-ERCOT portions of east Texas (U.S.). These capabilities will enhance grid visibility of the bulk power system in near real-time, enable detection of disturbances which may produce instabilities or outages, and facilitate sharing of information with neighboring regional control areas.

https://www.smartgrid.gov/project/entergy_services_inc_deployment_and_integration_synchro_phasor_technology

Power Grid Corporation of India Limited (PGCIL), The Unified Real-Time Dynamic State:

This Indian project will be the world's largest grid Wide Area Monitoring System, with 1300 PMUs and 34 PMU data systems. This development will enable nation-wide monitoring of power flows across the grid. Real-time data will ensure that PGCIL can intervene immediately to adjust and match electricity supply to demand.

http://www.alstom.com/press-centre/2014/2/alstom-achieves-a-new-milestone-for-indias-secure-electrical-grid/

SITUATIONAL AWARENESS

European Awareness System (EAS):

Launched in April 2013, and building on decades of TSO cooperation, the European Awareness System is an important collaborative tool for ENTSO-E TSO members across 35 European States. It covers Scandinavia, the Baltic States, the British Isles and Continental Europe, helping to ensure that energy consumers stay seamlessly connected during extreme weather peaks or system failures.

https://www.entsoe.eu/news-events/announcements/announcements-archive/Pages/News/entso-e-members-launch-the-european-awareness-system-to-help-keep-europe-switched-on.aspx

Renewables Integration Tool:

A tool which enables grid operators to use wind energy more cost-effectively to serve electricity customers in Idaho and Oregon (U.S.). Renewables Integration Tool (RIT) is a series of models and databases for forecasting weather conditions and the availability of wind energy resources.

http://energy.gov/sites/prod/files/2014/09/f18/IPC-SGIG-casestudy-Sep2014.pdf

SMART SUBSTATION

Implementation of process bus solutions increases station capabilities:

Powerlink Queensland, Australia is undertaking several projects trialing the implementation of IEC 61850-9-2 process bus to establish a valuable understanding of the technology developments and further refine the technology road map for implementation of IEC 61850 process bus.

http://tdworld.com/transmission/australia-leads-process-bus
http://www05.abb.com/global/scot/scot221.nsf/veritydisplay/afe7d21128b68e1fc1257c12004cb9aa/$file/1kha-001356-loganlea-2012-2-en.pdf

Third Party Tools for IEC 61850 substation modernization projects

Vattenfall, Sweden, is conducting a pilot project developing a process for IEC 61850 substation automation. The pilot project demonstrates how a third-party IEC 61850 tool can support the utility in efficiently structuring information during the specification as well as reviewing and documenting IEC 61850 deliverables. To get the full benefit of IEC 61850, Vattenfall has realized that all aspects of the standard need to be considered.

http://www.pacw.org/no-cache/issue/december_2014_issue/lessons_learned/third_party_tools_for_iec_61850_substation_modernization_projects.html

RELATED PROJECTS

ACTIVE DISTRIBUTION NETWORK

Grid4EU:

The project aims at testing in real size some innovative system concepts and technologies in order to highlight and help to remove some of the barriers to the smart grids deployment. It focuses on how DSOs can dynamically manage electricity supply and demand, which is crucial for integration of large amounts of renewable energy and empowers consumers to become active participants in their energy choices.

http://www.grid4eu.eu/;
http://www.iea-isgan.org/?c=5/112/366&uid=1310 (annex 1 project catalogue part 1)

IGREENGrid:

The IGREENGrid project focuses on increasing the hosting capacity for Distributed Renewable Energy Sources in power distribution grids without compromising the reliability or jeopardizing the quality of supply. The project is related to already existing demonstrations and the investigation of replicability and scalability of the developed solutions.

http://www.igreengrid-fp7.eu/

CUSTOMER ACTIVATION

Electricity Supply Board - Networks (IE), CER National Smart Metering Plan:

The project assessed: the impact of Time of Use pricing and billing/information stimuli on the customer behavior; and the available technologies for AMI roll out in an Irish context. The outcomes of both were factored into the cost benefit analysis for the full roll out of AMI in Ireland.

http://www.cer.ie/en/information-centre-reports-and-publications.aspx?article=c03aebf5-8048-456c-ba8b-33a79319a818
http://www.iea-isgan.org/?c=5/112/366&uid=1310

Reforming the Energy Vision

The New York Public Service Commission (U.S.) announced 2014 a plan called Reforming the Energy Vision. This initiative will lead to regulatory changes that promote more efficient use of energy, deeper penetration of renewable energy resources such as wind and solar, wider deployment of "distributed" energy resources, such as micro grids, on-site power supplies, and storage. These changes, in turn, will empower customers by allowing them more choice in how they manage and consume electric energy.

http://www3.dps.ny.gov/W/PSCWeb.nsf/All/26BE8A93967E604785257CC40066B91A?OpenDocument

Acronyms and Abbrevations

AC	alternating current
AMI	automatic metering infrastructure
BMS	business management system
CIM	common information model
CSC	current source convertor
CT	current transformer
DC	direct current
DER	distributed energy sources
DG	distributed generation
DLR	dynamic line rating
DMS	distribution management system
DR	demand respons
DSSE	distribution system state estimator
DSTS	distribution strain and temperature sensing
DSO	distribution system operator
EV	electric vehicles
FACTS	flexible AC transmission system
GIS	geographic information system
GPS	global positioning system
HVDC	high voltage direct current
HVT	high voltage technology
ICT	information and communication technology
IED	intelligent electronic device
IGBT	insulated gate bipolar transistors
LV	low voltage
LVGC	low voltage grid controller
MV	medium voltage
NIS	network information system
NCIT	non conventional instrument transformers
OHL	over head line
OLTC	on-load tap changer
PAC	protection and control
PDC	phasor data concentrator
PMU	phasor measurement unit
POC	proof of concept
PSS	power system stabilizer
PT	power transformer
PV	photovoltaic
RES	renewable energy sources
RTU	remote terminal unit
R&D	research and development

ACRONYMS AND ABBREVATIONS

SCADA	supervisory control and data acquisition
SVC	static var compensation
TO	transmission owner
ToU	time of use
TSO	transmission system operator
T&D	(power) transmission and distribution
VSC	voltage source convertor
VVC	voltage/var controller
WAMPAC	wide area monitoring, protection and control
WAMS	wide area measurement systems or wide area monitoring systems
XLPE	cross linked polyethylene