Spotlight on
Smart and Strong Electric Power Infrastructure

Best practice shared from the ISGAN Annex 6 case book

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***Abstract* — This paper summarize a number of smart-grid cases from the case book within ISGAN Annex 6: Power T&D Systems. The case book spotlights a number of projects sharing best practice in how to meet the challenge to develop the electricity network to become stronger and smarter using different approaches. For example how:**

- **Existing and new AC power transmission lines can carry more power by the use of smart technologies such as WAMS and Synchrophasors.**
- **HVDC lines with Voltage Source Converters can be used for interconnectors that also support the existing grid e.g. by avoiding voltage collapse.**
- **The use of smart voltage control concepts can increase the hosting capacity for distributed energy resources**

Keywords— smart grids, power transmission and distribution, ISGAN; synchrophasors; HVDC; WAMS; hosting capacity

I. Introduction

To reach a more sustainable future and to support the long-term CO_2-reduction goals, the full potential of renewable energy sources - a clean energy transition - is needed. At the same time stability, security of supply and quality of service for the electric power system must be secured.

The introduction in the generation mix of a continuously increasing share of generation from renewable energy sources (RES), the geographical spread of generation when increasing the amount of distributed production, as well as changing patterns of demand from new types of load such as electric vehicles, will create new challenges for the electric power transmission and distribution (T&D) systems. The on-going evolution of the power system, to cope with these challenges, is illustrated in Fig. 1.

To provide the real-time flexibility needed to efficiently handle the new operating conditions of the power grid, the T&D system has to become smarter and stronger. This requires increased knowledge and supervision of system behavior and wide area implementation of information and communication technology (ICT) for monitoring, protection, control, automation and visualization. There is further a need for additional controllable devices based on power electronics such as flexible AC transmission systems (FACTS) and high voltage direct current (HVDC).

The new energy landscape opens for solutions that can be made on different levels in the electricity system and increased interaction between different parts of the T&D system is required. This calls for new technical solutions, sharing of data, and at the same time new business models.

Next to the developments in the grid, there is also a new role for customers when time-dependent electricity prices, local generation, and customer as well as grid-side energy storage, all become increasingly feasible.

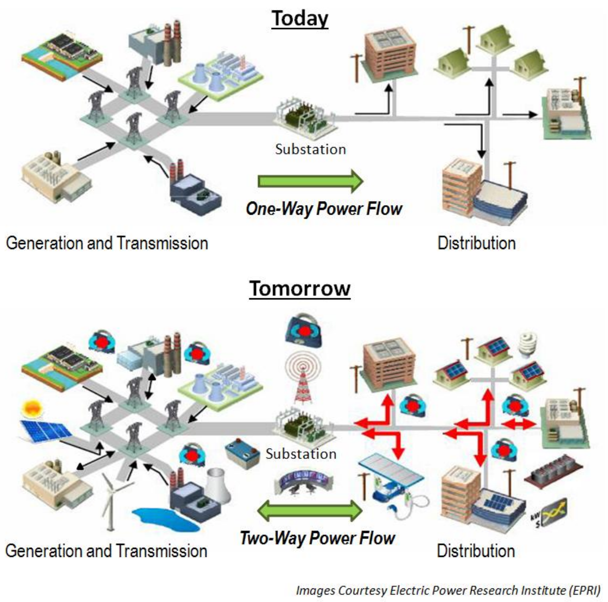

Fig. 1. Illustration of how the power systems are evolving towards including more RES and storage both at transmission and distribution level, more information and possibility to control, and more flexible loads.

This paper is based on the ongoing work with a case book within ISGAN Annex 6: Power T&D Systems. The case book spotlights a number of projects sharing best practice and different approaches on how to meet the challenge to develop the T&D network to become smarter and stronger.

II. ISGAN

ISGAN, International Smart Grid Action Network, is a mechanism for international cooperation with a vision to *"accelerate progress on key aspects of smart grid policy, technology, and investment through voluntary participation by governments and their designees in specific projects and programs."*

ISGAN is an initiative within the Clean Energy Ministerial (CEM) and an Implementing Agreement within the International Energy Agency (IEA).

The focus of ISGAN is a government-to-government cooperation in which 24 countries and the European Union are working together to support informed decision making on smart grid projects and systems. [1]

III. THE ISGAN ANNEX 6 CASE BOOK

There is no generic solution or size that fits all for the solution towards the smart and strong grid. Different countries have different challenges, will use different solutions to those challenges, and have reached different maturity in the implementation of those solutions. At the same time there are generic solutions and findings from experiences that can be adapted by other countries to make local implementation faster and more efficient. Smart grid solutions are also found across the entire electrical system, from the high voltage transmission grid, through the distribution grid and finally on consumer level.

ISGAN Annex 6 will be publishing a case book where the member community has contributed with specific projects to illustrate applications, solutions and technology from different countries and from different levels in the electrical system. The cases are selected to cover the following key drivers for building a smart electrical grid: To integrate renewables (R); To improve the market (M); To activate customers (C) and To increase security of supply (S).

Version 1.0 of the case book covers a range of examples, as listed in Table I:

TABLE I. CASES INCLUDED IN THE ISGAN ANNEX 6 CASE BOOK VER. 1.0

Country	**Case**	**Level**	**Driver**
France	Smart Substation	TSO/DSO	R, S
Ireland	East-West HVDC Interconnector	TSO	R, M, S
Sweden	Embeded HVDC link	TSO	R, M, S
U.S.	Wide Area Reliability	TSO	R, M, S
Italy	WAMS Experience in Italy	TSO	S
South Africa	Situational Awareness	TSO	R, S
Austria	Active Distribution Network	DSO	R
Italy	Customers´respons under time-dependent electricity prices	DSO	C

Of course there are many more good examples of smart grid projects all over the world, beyond those covered in the ISGAN Annex 6 case book. Further information is for example found in [2], [3], [4], [5].

The ISGAN Annex 6 case book will be an evolving document that is periodically updated with new projects, both regarding transmission and distribution.

Fig. 2. The ISGAN Annex 6 case book will be officially published during spring 2015.

The ISGAN Annex 6 case book will be published on the ISGAN webpage: http://www.iea-isgan.org/, see Fig. 2.

IV. THE SMART TRANSMISSION SYSTEM

The new challenges to which the electrical network is exposed require a smart and strong infrastructure where the need for flexibility is an important requirement. The main mechanism to make the power system more flexible is to allow for faster changes in power flow. During the last 20 to 30 years the digital technology has spread to almost every aspect of our life and this digital evolution is providing the power system with new and better solutions. Solutions are available for power system management and automation with faster communication of more data. Solutions are also available for high voltage technology with the development of power electronics for FACTS, such as static Var compensators (SVCs) or thyristor controlled series compensators (TCSCs), and HVDC.

A large majority of existing and new transmission lines are based on AC technology. Controllability of AC lines is traditionally low and the usable capacity of lines is normally not determined by thermal rating but rather by stability criteria. To allow better utilization of existing and new lines, two main elements are required: more information and more control of the power flows.

More control of the power flows in the transmission system is possible with power electronics for AC and DC. The need for more information is fulfilled by faster and more accurate ICT. Together, ICT and power electronics form the core technology to design and operate a smarter and stronger grid, which is illustrated by several cases presented in the forthcoming sections.

A. East-West HVDC Interconnector

The Irish transmission system operator (TSO), Eirgrid, shares a case in the case book where they have improved the security of supply in their network by providing additional capacity.

This was done by building the East-West Interconnector (EWIC), a voltage source converter (VSC)-HVDC based link, which connects the electricity transmission grids of Ireland and Great Britain. The interconnector has a capacity of 500 MW (equivalent to approximately 10% of the Irish peak demand) and also provides a range of ancillary services, such as frequency response; reactive power provision; and includes ‘black start’ capability for both Ireland and Great Britain.

The project is instrumental for Ireland to reach its renewable electricity targets but also greatly contributes to lowering the electricity price for consumers, as shown in Fig. 3.

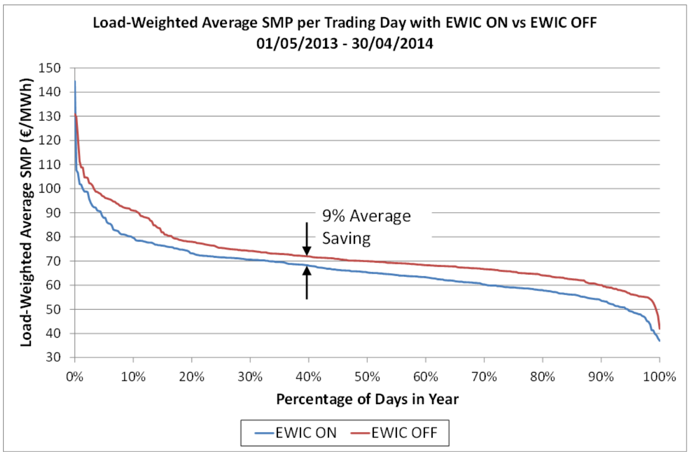

Fig. 3. Indications since the beginning of commercial operation suggest that EWIC is facilitating competition and exerting downward pressure (9%) on system marginal price (SMP) in Ireland due to better utilization of common resources rather than relying on local solutions.

The EWIC project had three key objectives.

- To improve the security of supply by providing additional capacity.
- To exert downward pressure on wholesale electricity prices in Ireland by providing direct access to the larger Great British electricity market.
- To allow the export of excess power from Ireland at times of oversupply to the Irish network.

B. Embeded HVDC link

Also the Swedish TSO Svenska Kraftnät has used VSC-HVDC technology to make their network smarter and stronger by building the South West Link (SWL), as shown in Fig. 4.

This link combines different types of technologies: overhead AC and DC, as well as underground DC. Using overhead techniques helped keeping the cost down. Combining DC overhead line with a cable prevented a large delay as no new right-of-way was required. The DC technology makes it possible to control the power flows and increase the transfer capabilities.

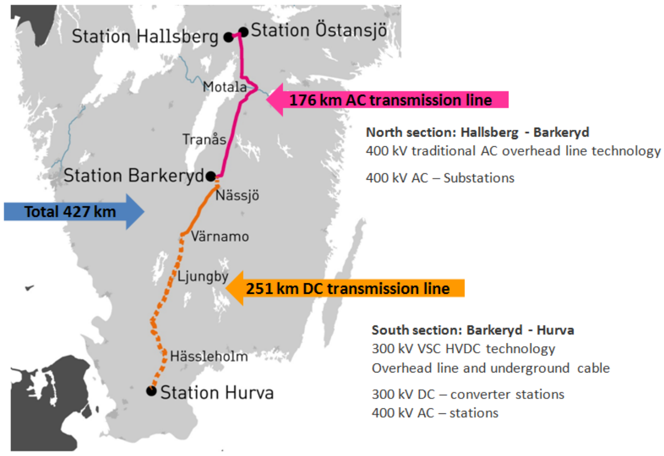

Fig. 4. Map presenting the location of the different techniques used in the SWL, from north to south: 176 km AC overhead line followed by 61 km DC overhead line and 190 DC cable.

The main driver behind SWL is to increase the reliability and improve security of supply to the south of Sweden. Increasing the capacity to the southern part of Sweden became especially important after the decommissioning of a nuclear power plant which led to increased capacity limitations related to voltage instability.

The South West link is also an important part in the necessary development of the national grid, required to enable the introduction of renewable energy as planned in accordance with Swedish and EU energy policy objectives.

C. Wide Area Reliability

Important technologies for getting more information are wide area management systems (WAMS) and phase measurement units (PMUs).

The United States share in a case for the case book their experience from The Bonneville Power Administration (BPA) synchrophasor project.

BPA is receiving data from 126 PMUs at 50 key substations and large wind-generation sites throughout the Northwest of the United States. In addition, BPA has also developed an application capable of assessing the dynamic performance of its generating fleet within minutes of a power grid disturbance.

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. 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 control centre together with operational displays.

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

Improved understanding of power grid performance 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.

D. *WAMS experience in Italy*

Also a second case is related to WAMS and PMUs, where TERNA, the Italian TSO, shares their operational experiences of the WAMS for the synchronised monitoring of the Italian power grid interconnected with the Continental European system. Currently, 55 substations in Italy are monitored by PMUs, mainly on 400 kV level.

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, also in view of implementing Wide Area Control/Protection System (WACS/WAPS) solutions.

Fig. 5 A typical geographic display of the WAMS platform. The background colors of the map depend on the voltage magnitude

The WAMS platform, available to operators in the control room, provides a valuable support to operation. Real-time plots and charts of system quantities such as phase angle differences, and the output of monitoring functions such as oscillation identification, allow operators to better track system stress and dynamic phenomena, and evaluate the possible impact of switching actions. An example of a typical geographic display is given in Fig. 5. Cooperation with other countries of the same synchronous area, in the form of real time PMU data exchange, has proven being particularly useful.

E. *Situational Awareness*

Another possibility to improve the network operation based on increased information is the “Situational Awareness System” that is being implemented in South Africa.

The idea with situational awarenesss is to combine the electrical interconnected power system with environmental conditions and by doing so being able to more accurately anticipate future problems to enable effective mitigation actions.

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

The South African utility, Eskom, describes a Proof of Concept which aims at investigating the feasibility, requirements and development of a visualization server stack for the grid situational awareness concept. The Proof of Concept focuses on integrating various data sources. This data enables Eskom to be able to make better decisions. Experience is essential for implementing and applying the data.

The majority of the time in this project was focused on collaborating with different providers of data, possible users of the data throughout the business as well as system architects in order to establish a road map for future implementations regarding the integration and visualisation of data from disparate sources.

Information is needed from all parts in the system and advanced, accurate and fast applications are required. Within a sound business management system (BMS), supervisory control and data acquisition (SCADA) and other Network Information Systems (NIS) will enable better, automated management of energy, assets, distribution and demand-side activities as well as substation automation. This complex interdependence, which is illustrated in Fig. 6, raises the urgent need for interoperability among different components and “systems of systems” from diverse vendors that need to “talk” to each other.

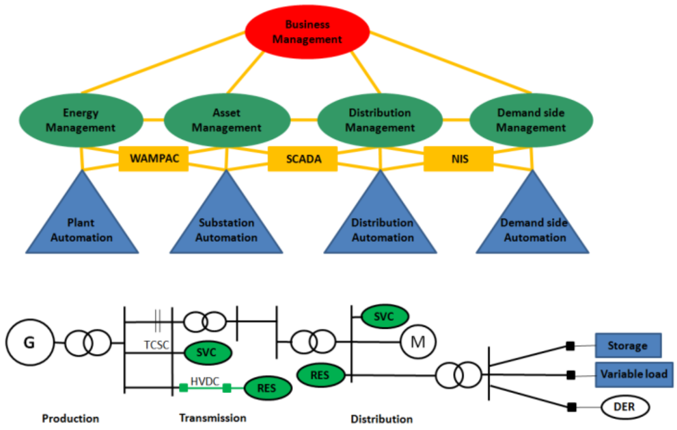

Fig. 6 Illustration of the information interdependencies of the power system including for example wide are monitoring, protection and control (WAMPAC), supervisory control and data acquisition (SCADA) and network information systems (NIS).

Also the evolution in the grid operation sector will require an even closer cooperation between transmission system operators and distribution system operators. Further discussions regarding this topic can be found in [5].

F. Smart Substation

France has in the Smart Substation project an industrial pilot project with experimentation of a new technological package including new advanced control functionalities. The project is executed by a consortium led by the French TSO, RTE.

The project aims to design, build, test and operate two fully digital smart substations by 2015: one transmission substation; and one distribution substation. The distribution substation represents the interface between the transmission and distribution systems. The digitalized architecture will be deployed on existing substations.

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

The intention with the project is to enable the electrical power equipment to work closer to their physical limits. At a national scale, a transmission system using smart substations is able to transport more energy than a traditional grid. The development of digital substations enables, not only locally but also at a national scale, an optimization of the development and reinforcement of the transmission grid. The introduction of digital technology in all transmission substations is also a technological solution that will contribute to reaching the European commitments in terms of renewable integration.

V. DISTRIBUTION GRIDS AND CUSTOMER ACTIVATION

A. Distribution Grids

The distribution grid has often been built with very traditional technologies offering low cost and high reliability. But with the described changes in the energy system, new solutions must be found to allow an efficient way to meet the new challenges, without endangering the reliability or resulting in high costs. Increased controllability as well as new market models will provide the opportunities to meet these challenges. Tests and implementation of smart functionality in the distribution grid has demonstrated increased capability to operate the grid safely closer to physical capability limits and increased the hosting capacity for renewable electricity production, without the need for investments in new primary infrastructure.

B. Active Distribution Network

An example of projects aiming at increasing the hosting capacity for renewable electricity production in low and medium voltage networks is given in the Austrian case in the case book.

The main goal of the Austrian project is to find an efficient way for the integration of renewable electricity production with regard to optimized investment by maximizing the utilization of the existing asset base.

The main challenge of integrating distributed energy resources (DER) in rural distribution networks, as pointed out in the case book, is to keep the voltage within the specified limits, which the project aims at doing through the use of smart planning, smart monitoring and smart control.

For medium voltage networks with high share of distributed generation, two different control possibilities have been investigated for maintaining the voltage within its permitted band: a stand-alone solution integrated at substation level based on measurements; and a solution in a distributed management system based on state estimation. Both solutions are controlling setpoints of the on-load tap changer transformer and generators.

In the project led by Austrian Institute of Technology, AIT, it has been demonstrated that the implementation of voltage control concepts in medium and low voltage networks can increase the hosting capacity significantly.

C. Customer activation

One of the drivers pointed out to build smart grids is the activation of customers. Activation of customers includes activating customers with own production, which increases the amount of renewables, but it also includes different ways to change the customer load profile. A smoother load profile increases the efficiency of the system. Activation of customers is a very wide area, but this could be achieved among others by getting more consumers participating, directly or indirectly, in the electricity market and through new tariff structures such as time-of-use tariffs.

D. *Customers´ respons under time-of-use tariffs*

The second Italian case describes their experience of introducing time-of-use tariffs and the effects of such tariffs on electricity consumption by residential customers in Italy. The long-term goal is to induce the Italian customers to adjust their consumption according to the abundance or scarcity of electricity. This will for example lead to less need of reinforcements in the network due to a reduction of the load during peak hours.

The results show that, even if there was 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 role of the customers in shaping their energy consumptions as active users to face time-dependent electricity costs has been shown in the project. The research project was run by RSE (the Italian TSO) in collaboration with and under the patronage of AEEG (the Italian regulatory agency).

VI. CONCLUSIONS

The purpose of this article and of the casebook is to illustrate lessons learned and to highlight a wide range of applications related to power T&D systems or smart grids. The examples are intended to support the value smart grid solutions can bring in order to integrate renewable energy, improve the market, activate customers, and increase the security of the electricity 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 supply.
- Sweden: HVDC advanced voltage source converter (VSC-HVDC) technology increases transmission capacity and helps avoiding 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: VSC-HVDC 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 capacity can be increased without adding primary infrastructure.
- France: Smart substations demonstrate how electrical equipment can operate closer to its limits, thereby minimizing investments. 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 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.

VII. ACKNOWLEDGMENT

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