The IEA Implementing Agreement for a Co-Operative Programme on Smart Grids

International Smart Grid Action Network (ISGAN)

Annex 6 : Power T&D Systems

The Smart & Strong Grid:

Connecting Clean Energy with People

VISION: To create a seamless cost-effective electricity system, from generation to end use, capable of meeting all energy demand and capacity requirements, while allowing consumer participation and electricity use as desired.

MISSION: To ensure a “future-proof” interoperability among products, systems and participants in the digital power system. This can be compared with a massively multiplayer online role-playing game (MMORPG) with new interactive roles and rules. This system will dynamically interact with new market actors, system operators, power producers, service providers and end users (some of whom own generation and could be considered as “prosumers”).

THE CHALLENGES: The transition to clean energy technologies is based on large-scale wind, solar and hydro energy as well as distributed resources, such as PV solar cells. This variable generation requires planning ahead for stronger and smarter power grids, enabling also flexible consumption through demand response and energy storage. The “digital power engine”, driven by power electronics and information and communication technology (ICT), is ready to be deployed but requires the decisions, rules and roles defined by policy makers and regulators as well as understanding and motivation from all actors in this MMORPG. The digital technology can be applied for the need of each region. The long-term and sustainable planning of all smart and strong power grids will require a system view in which global know-how and best practice can be shared. This is a global challenge that requires global cooperation.

THE POSSIBILITIES: The evolution of both power electronics and ICT provides new digital tools to design a smarter and stronger power system with the required flexibility. These digital technologies provide improved visibility (the ability to “see” an event or condition), grid understanding (the ability to “know” what is happening or about to happen) and grid flexibility (the ability to “do” something appropriate in response).

This technology brief has been prepared by ISGAN Annex 6 Power T&D Systems

The Challenge:

To balance generation and load at every moment – and everywhere!

Figure 1: The power system has to be balanced in two directions: active power (P) for frequency and reactive power (Q) for voltage. This can be seen as a 3D power globe rotating at the power system frequency and maintaining different specified voltages - on all levels.

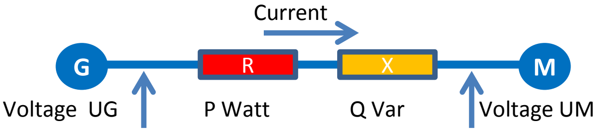


Figure 2: Active and reactive power from the generation (G) to the motor (M)

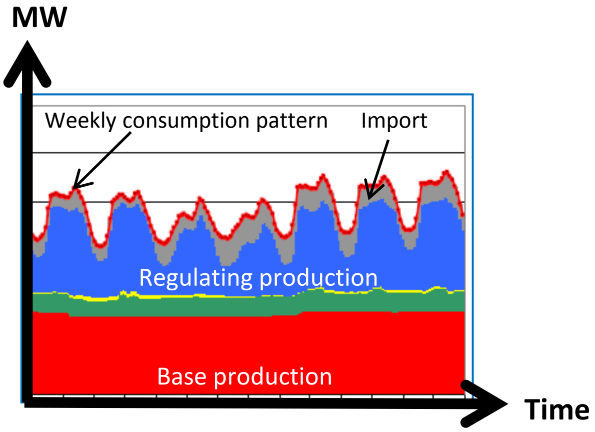


Figure 3: Example of one week balance of supply and demand

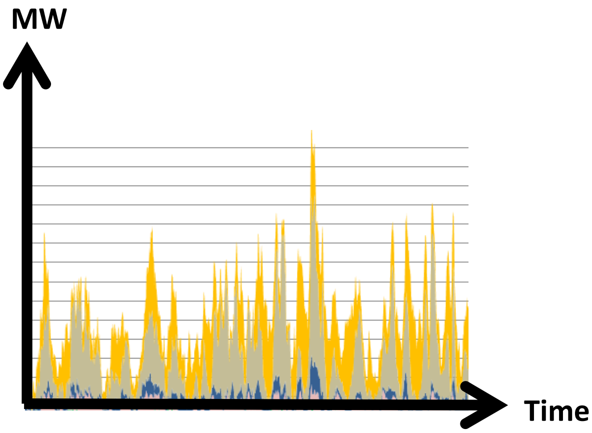


Figure 4: Example of variation of wind production

Supplying electricity to end-users has traditionally been a balancing act among three elements. Large power plants **generate** electricity by transforming primary energy sources (such as fossil fuels or hydro resources) into an electrical current that can be sent to consumers through **transmission and distribution** networks. But the nature of electricity adds a complex dimension: because it cannot be stored, power companies need to anticipate – down to the minute – the level of **demand** (i.e. how much electricity will be needed by whom).

Generation: Electricity can be generated as alternating current (AC) and direct current (DC). For decades, AC has been used for power delivery. Described very simply, in AC systems rotating generators produce the power to drive rotating motors with the same speed at a defined frequency (typically 50 Hz or 60 Hz). In turn, these motors absorb and transform into mechanical power the three-phase AC electricity known as active power, measured in watts (W) and millions of watts (MW).

Transmission and distribution (T&D): Each time an electrical current passes through transmission lines and cables, or through the transformers (a key component that allows interconnection of lines of different voltages), some electricity loss occurs (Figure 2). Resistance (R) causes active power losses that influence the frequency while reactance (X) causes reactive power losses that affect the voltage. In the case of long lines with large reactance, significant voltage drops can occur between generated voltage (UG) and motor voltage (UM). Within a given system, these voltages must be maintained within strict limits every moment.

Demand: Balancing is further complicated by the fact that electricity consumption of end-users changes throughout the day (or week, month or year). Charting peaks and valleys in demand patterns for one week demonstrates how base production from large power plants (e.g. nuclear and thermal) has to be supplemented by regulating power (e.g. hydro) or through imports from a neighboring power system (Figure 3).

Enter two new dimensions: variable supply and variable demand
A characteristic common to renewable energy sources (RES) is that availability of the primary sources – wind, sun or water – also varies. As a result, widespread RES deployment will cause large and uncertain variations in magnitude and time of produced power (Figure 4). Finally, consumers are entering a more dynamic relationship with energy systems. Rather than remaining passive recipients of energy services, they are more empowered to install new technologies (such as solar panels and electric vehicles) that can generate – and sometimes store – electricity. If they generate more than they use, the possibility exists to sell the excess. Moreover, incentives (known as demand-response schemes) prompt users to change their consumption patterns.

Power systems of the future must be designed with the capacity to meet maximum demand while managing a more diverse and more variable generation portfolio: electricity grids need to be strong and smarter!

The Solution:

Create “systems of systems” that operate in real time

Reliable delivery of energy services under conditions of greater variability requires a transformation of present energy networks into systems able to integrate effectively parallel advances in power electronics and in information and communication technology (ICT). This integration will enable stronger, more efficient and more controllable grids. Deployment and operation of this stronger and smarter infrastructure requires early planning and preparation.

Advanced power electronics: The proven ability to use both AC and DC power within a power grid (Box 1) is critical to develop smarter and stronger grids that have the flexibility to deliver power as supply and demand become more variable. Three key elements need to be considered from the outset.

1. Install sufficient capacity to ensure sufficient supply in the presence of large variations and longer periods of low generation that characterize RES. Because of their variability, wind and solar will require more installed power in MW to produce the same energy in MWh as current base-load plants.
2. Distribute flexible AC transmission systems (FACTS) devices – such as series compensation (SC) and static Var compensation (SVC) – to control and balance the voltages.
3**. Use high voltage direct current (HVDC)** to control the power flow and achieve two key advantages:
- HVDC improves controllability in hybrid AC and DC systems because with direct current you can direct the current.
- HVDC is suitable for long overhead lines and cables, and for long sub-sea interconnection, because it reduces losses and reactive power needs.

Box 2 - Evolution of HVDC technology: HVDC convertors can interconnect power systems by rectifying AC to DC and inverting DC to AC. The “classic” HVDC with thyristors is used mainly for bulk power transmission and interties. ±800 kV is in service or in construction (China and India). The 580 km HVDC link connecting Norway and The Netherlands is the world’s longest submarine high-voltage cable. The more recently developed voltage source converter (VSC) with transistors can be described as a “digital power machine” capable of controlling active and reactive power. HVDC VSC is in service in many countries, and in progress for important projects: a 500 kV HVDC cable linking Norway and Denmark; a 260 km double HVDC link in Southern Sweden; the 450 km NordBalt connection between Lithuania and Sweden; and the connection of several offshore wind projects in Europe.

Box 1 - Building on 60 years of experience: The world’s first 400 kV high voltage AC (HVAC) transmission line was installed in Sweden in 1952 and upgraded in 1954 with series compensation to transport hydropower about 1000 km. This was the introduction of what is known as Flexible AC Transmission (FACTS). That same year, Sweden installed the first commercial high voltage DC (HVDC) link to provide service to the island of Gotland. Today FACTS and HVDC are increasingly used in combination around the world to ensure a strong and smarter grid.

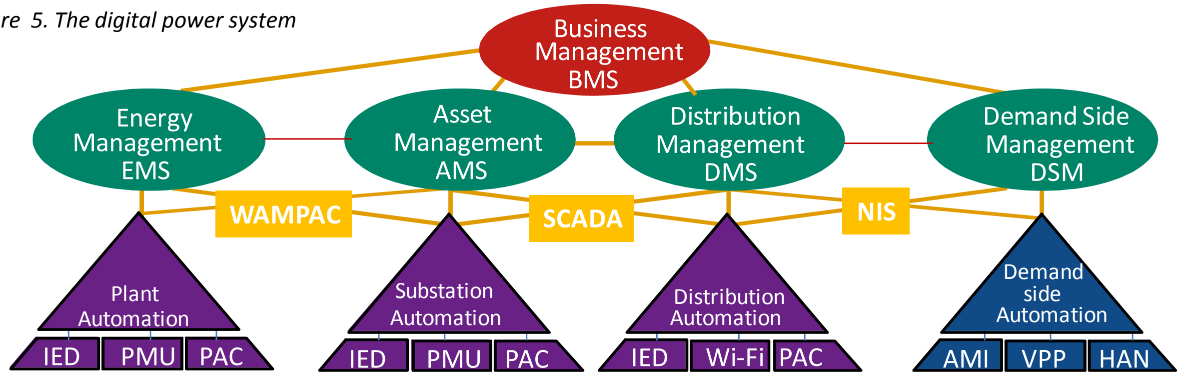
Information and communication technology (ICT): Fast and reliable exchange of information – the foundation for a smart grid – will require a complete ICT infrastructure that connects distributed sensors in the substations to both traditional and new users of this information and incorporates actuators to rapidly control the system. This implies standardized and interoperable products and “systems of systems” complying with the IEC 61850 standard series.

The architecture of the ICT infrastructure includes several layers, with distributed and centralised functionality (Figure 5). Real-time digital interaction across the power system is done by intelligent electronic devices (IED) for protection and control (PAC), phasor measurement units (PMU) or other distributed intelligence communicating via fibre optics or Wi-Fi. Automatic metering infrastructure (AMI), virtual power plants (VPP) and home automation networks (HAN) are examples of other sub-systems.

Automation of the power utility, the substation, distribution and consumer demand – coupled with wide-area monitoring, protection and control (WAMPAC), supervisory, control and data acquisition systems (SCADA) and network information systems (NIS) – will empower system operators. An overarching business management system (BMS) will handle transactions of energy and of balance and reserve power.

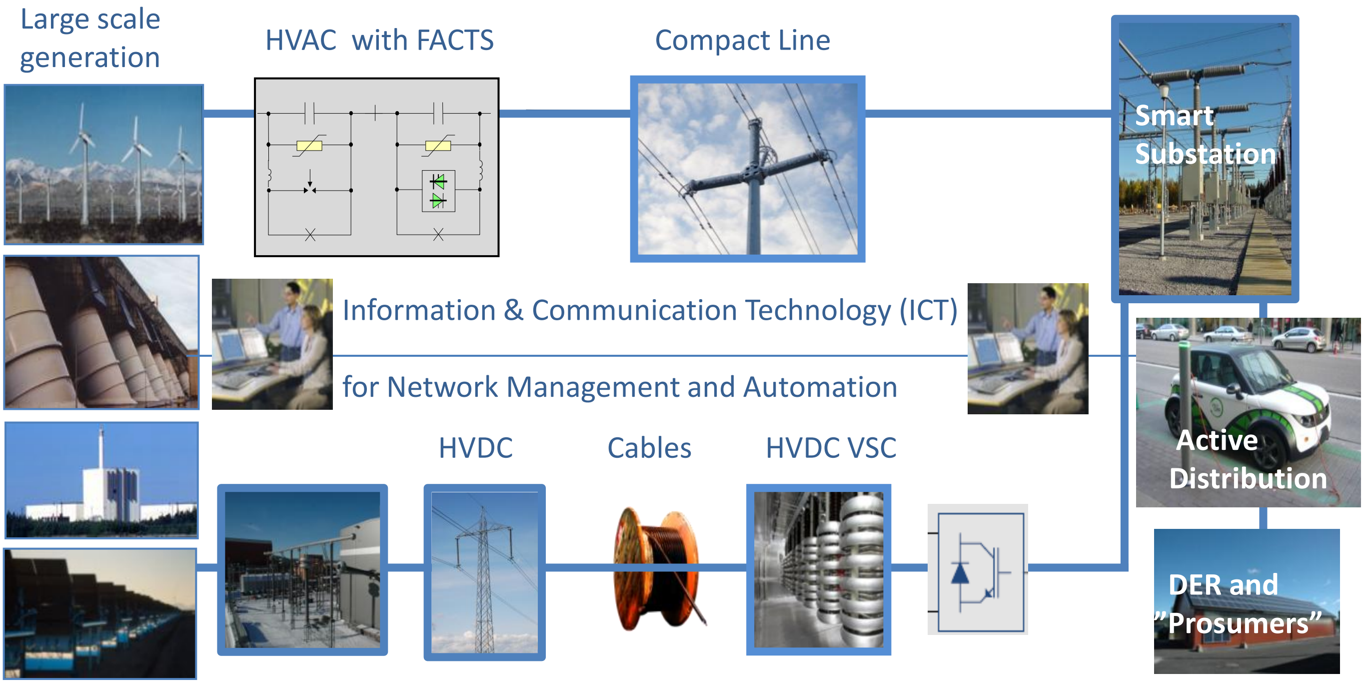
The evolution of power electronics has led to new possibilities for FACTS and HVDC technology. HVDC technology can be an alternative to building new OHL and also makes it possible to convert existing lines from AC to DC. Development of fast DC breaker technology supports the design of larger DC grid systems. Coupling these technologies with enhanced ICT solutions will give future power systems operators better control based on increased observability of network conditions to operate strong and smart grids.

Figure 5. The digital power system



I-PoSItion CE^4 Technology Brief

Intelligent Power System Information for a Clean Electric Energy Efficiency Evolution



Large scale generation

HVAC with FACTS

Compact Line

Smart Substation

Information & Communication Technology (ICT)

for Network Management and Automation

Active Distribution

HVDC

Cables

HVDC VSC

DER and "Prosumers"

With flexible AC transmission systems (FACTS) and high voltage DC (HVDC), the basic technology is available to support the "Clean Electric Energy Efficiency Evolution" (CE^4) and the transition to a low-carbon society. A smart and strong grid provides the infrastructure for efficient power delivery of clean energy with low losses – a key element of a sustainable energy future. The capacity to transmit both AC and/or DC power, together with a high-performance ICT infrastructure for automation and wide-area supervision, is ready to be deployed as the backbone of a smart and strong grid that can be efficiently managed to control power flows. This makes it possible to:

- ☐ Harvest renewable energy sources from rivers, oceans and deserts.
- ☐ Integrate small- and large-scale hydro, wind and solar power.
- ☐ Upgrade existing power transmission and distribution systems.
- ☐ Electrify and empower communities and infrastructure.

Strong and smart grids are an integral part of the "Clean Electric Energy Efficiency Evolution". Urgent investments in power T&D infrastructure are required to ensure grid reliability, stability and quality of service. This requires money, time and the involvement of many stakeholders: collaboration across the value chain is needed to achieve the transition in a cost-efficient manner.

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ISGAN, also known as the Implementing Agreement for a Co-Operative Programme on Smart Grids, functions within a framework created by the international Energy Agency (IEA).