Power networks for non-technicians

Reliable electricity networks, from power generation to the plug

This document seeks to simplify the highly complex world of power transmission and distribution by explaining the basics in a clear way. We want to break down the barriers to understanding created, among other things, by industry-specific acronyms, like FACTS, HVDC and SCADA. The intention is to provide the general media or other interested non-technicians with a brief guide.

History
The electric utility industry began at the end of the 19th century. At that time the founders of ABB's predecessors were the first to transmit electricity via power lines. They invented the three-phase system which efficiently generates power from three windings of copper wire in generators and transformers. The use of electricity has been growing ever since and it is vital to virtually every aspect of our economy. As shown after a power outage, the public only appreciates so-called commodities when they aren't there. The real challenge is to bring the electric power from the producer to the consumer efficiently and cost effectively.

Power generation
Consumers expect electricity to be available whenever they plug in an appliance, turn a switch, or open a refrigerator. Satisfying these instantaneous demands requires an uninterrupted flow of electricity. In order to meet this requirement, electrical power producers operate several types of electric generating units, powered by a wide range of fuel sources. These include fossil fuels (coal, natural gas and petroleum), uranium, and renewable fuels (water, geothermal, wind and other renewable energy sources). Power stations are often brought online at different times of the day in order to meet the peaks and troughs of demand.

Power transmission and distribution

Power transmission and distribution lines (shortened to 'T&D' by professionals and engineers in the business) provide the physical transport infrastructure to transmit electricity from the generation sources to customers. High-voltage **transmission** networks (generally these are rated between 115,000 and 800,000 volts (usually written 115 kV to 800 kV) take the power from the source of generation to areas where there are concentrations of customers. From there, the **distribution** system moves the electricity to where the customer uses it at a business or home.

Transmission systems are designed to move energy instantly from the generator to the consumer since there is generally no long-term storage capability for electricity.

(Although in August 2003 ABB completed an installation in Fairbanks, Alaska of a battery-based energy storage system which is able to feed the power grid in an emergency with 40 MW of power for 6-7 minutes, or 27 MW of power for 15 minutes - long enough to cover the time between a system disturbances and diesel-powered back- up generators coming online. To give an idea of the scale of this back-up system, the battery is larger than a soccer field.)

Electricity, when transmitted, flows over all available paths to reach the customer and it cannot be easily directed in one particular way. Therefore, the buying and selling of electricity requires the direct coordination and proactive monitoring of the electrical systems with sophisticated IT programs. If a problem develops somewhere, the impact affects other operations elsewhere.

In the United States, ten industry reliability councils were established that operate three independent electrical systems (called power grids) to handle this coordination. Within each of these power grids, there are different types of equipment and facilities that are owned by many different organizations (commercial companies, cities etc). Yet, each system is operated in a coordinated and unified manner within its power grid. However, since the three power grids are not simultaneously linked together, electricity does not flow between them.

Transformers
Transformers help solve the problem of sending electricity over long distances. They transform electricity from one voltage to another. They are used to increase, or 'step up' the voltage from the power source to be carried at several hundred kV over the **transmission** lines and then again to reduce, or 'step down' the voltage to the **distribution** network where it can be used in the home or office at 115 or 220 volts.

ABB is the world leader both in power and distribution transformers – in the 1990s it acquired the transformer assets of some of the world's best-known suppliers (Westinghouse, General Electric, National and Stromberg), having merged the leading European transformer manufacturers ASEA and Brown Boveri to form ABB, in the late 1980s. This experience and know-how is unparalleled and is today augmented by ongoing industry-leading research and development, not only in transformers, but also in high-technology T&D solutions.

GIS (gas-insulated switchgear)
New developments in conventional technologies now allow large amounts of power to be transmitted unobtrusively. For example, power can be transmitted at 400 kV and more right into the heart of a city through cables laid in underground tunnels. And gas-insulated switchgear (GIS) enables compact indoor substations, designed to switch this voltage, to be shrunk into about one fifth of the size of a conventional AIS (air-insulated switchgear) station. A substation is simply a facility that converts and distributes power.

GIS substations can even be retrofitted into existing buildings or buried underground. This reduction in the plant's 'footprint' can often release valuable city-center development land. ABB's product range covers the full range from low-voltage (below 1,000 volts) to medium-voltage (1,000 – 50,000 volts) up to extra high-voltage of 800 kV GIS.

FACTS
FACTS is a generic – or industry – acronym standing for Flexible Alternating Current Transmission Systems. It's a term covering a number of technologies that enhance the security, capacity and flexibility of power transmission systems. The technologies can be installed in new or existing power transmission lines. Examples are:

- Series Compensation can be fixed or controllable. The latter is called Thyristor Controlled Series Capacitor (TCSC)
- Static Var compensation (SVC) can be used to control voltages. The most advanced version is called SVC Light™

ABB's FACTS devices can enable more power to flow on existing power lines and also improve voltage stability. Capacity can be increased by more than 100 percent. They also make the system more resilient to 'system swings' and disturbances.

HVDC transmission

High Voltage Direct Current (HVDC) power electronic systems allow bulk power flow across regions (typically several hundred miles using either or both overhead lines and sub-sea cables) without troublesome 'loop flows'. Loop flows are a characteristic of interconnected AC systems on which there is always a challenge to synchronize currents and loads without causing an outage. Loop flows can unsettle grids.

The HVDC system provides support and performance enhancement for the surrounding AC grid. ABB's HVDC links are often regarded as the solid and reliable backbone for any electricity transmission system because they offer built-in overload control and can be fully loaded without increasing the risk of cascaded line tripping. This high availability makes HVDC an increasingly attractive investment for utility and other power transmission companies and organizations wanting to guarantee reliability and security of electricity supply.

HVDC back-to-back systems are able to interconnect independent power grids. Hence, this technology enables power flow from one grid to another and generators in both grids can be used to secure the supply of electricity. In addition, this technology can improve both voltage and frequency stability in both grids.

HVDC Light™ transmission

In addition to the benefits of traditional HVDC, this latest technology offers enhanced voltage control. It also offers so-called 'black start' capability. Black start means that it can power up networks that have suffered 100 percent failure. Often power plants need to be supplied power for their auxiliary systems that run the power plant before the power plant itself can begin generating power itself.

ABB's unique HVDC Light™ technology proved its worth during the outages in the U.S. in mid-August when the Cross Sound Cable was brought into commission. Once permission was given for it to be put into operation, it quickly enabled engineers to re-establish a reliable flow of power to Long Island and stabilized the voltage in Connecticut, through advanced voltage support services.

HVDC Light™ is designed for lower capacity (up to 350 MW) rather than conventional HVDC transmission, but has the advantages of being quicker to install and requires about a third of the physical space needed by conventional designs. All of ABB's HVDC Light power transmission lines have been installed either underground or underwater. This is why HVDC Light is referred to as "invisible transmission".

In operation it helps to stabilize the network, and gives independent control of power and voltage, all of which contribute to reducing the risk of faults. If network faults do occur, HVDC Light™ can, like HVDC, become a focus for reliability on the network because it cannot be overloaded and will not pass on cascade tripping. If other parts of the network fail, HVDC Light™ can re-start, or 'black start' an outaged system – in other words it does not need to rely on an operable AC system for start-up.

ABB's HVDC Light™ technology is unique and well proven – to date 16 HVDC Light™ convertors are in operation in six plants with a total of 500 km of underground and sub-sea cable already installed and in service.

HVDC Light™ is not an alternative solution to standard HVDC, but is suited to smaller needs, possibly where underground cables are specified by the utility or there is the need to isolate two independent AC systems.

SCADA

SCADA stands for Supervisory Control And Data Acquisition. A SCADA system allows the power network operator to view and control the status of many aspects of the network. Computer power is used to automate many of the operations. ABB's real-time wide area monitoring and control of power systems allow grid-wide monitoring and control of the power flows, transmission limit calculations and power plant operation. Advanced control systems, system protection, communication and automation applications can significantly improve the capacity and reliability of existing power transmission and distribution networks.

Network modeling

Network modeling allows the key causes of poor reliability to be identified and addressed. Advanced modeling on a system-wide basis, mirroring the electrical and operational constraints and performance of the real network, allows investment to be targeted efficiently. In addition, it is possible to assess the potential variation of performance from year to year, again identifying and predicting the need for future investment.

Life extension
In conjunction with a planned and sustained program of investments, modern materials and analytical design can often allow manufacturers to upgrade economically the capacity of existing equipment, improving its reliability and increasing its useful life.

Why systems trip and how this can be prevented
Both the U.S. and Europe operate very large synchronous AC electric power systems. These systems are good for getting power to where it is needed, but also prone to passing on 'trips' or power outages throughout a network. Why?

In these AC systems, the power flow in the different branches connecting power generation with where the power is used (known as 'load'), is governed by the principle of "least resistance". This means that if several parallel paths connect generation to load the path of "least resistance" will carry a major part of the flow, while a path of higher resistance will take on a smaller part of the total flow, and so on.

Since there is no way to 'steer' the power, it is shared by the network components (lines, cables etc) in what is known as a "free-flow" mode. (The physical properties of power lines, cables etc. govern their "resistance" to the flow).

Consequently, if one or several branches are tripped in such a network, power will automatically redistribute itself over the remaining paths. So, for each lost branch the remaining ones must take on more power and the redistribution of power may involve branches and paths in ever growing loops. This means that a disturbance (leading to the tripping of the first branch) can travel far and cause other branches to be tripped by relay protection. This is the so-called "domino effect". (When A fails B fails, and when A&B fail C fails as well).

One way to avoid this type of problem is to limit the size of "free-flow" networks and to interconnect the resulting "sub-network" via links that have the ability to control power flow and avoid unwanted electric interactions between the two sub-grids. This reduces the impact of a disturbance by de-coupling the networks involved and enables a power loss to be confined to a local area, instead of cascading throughout the grid.

High Voltage Direct Current (HVDC) and HVDC Light™ technology allows the flow of power across a DC link to be controlled, and effectively decouples the interconnected systems, thus preventing the domino effect having a network-wide effect.

This approach has the advantage of enabling network operators to benefit from power exchanges in a large power system, while avoiding the drawbacks of a completely free-flow synchronous network when multiple disturbances occur.

This concept is not new. It was mentioned in 1996 by American authors from the Oak Ridge National Laboratory, New England Power Service Co. and Power Technologies Inc. (a consultant). Again the same idea was recalled by Mr. George C. Loehr immediately after the August 14 U.S. blackout. Mr. Loehr is member of the executive committee of the New York State Reliability Council and serves as chairman of its Reliability Conformance Monitoring Sub-Committee.