# *Power Systems with Power Electronics*
## *SMART GRID*

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***Abstract***-*Power electronics can provide utilities the ability to more effectively deliver power to their customers while providing increased reliability to the bulk power system. In general, power electronics is the process of using semiconductor switching devices to control and convert electrical power flow from one form to another to meet a specific need. These conversion techniques have revolutionized modern life by streamlining manufacturing processes, increasing product efficiencies, and increasing the quality of life by enhancing many modern conveniences such as computers, and they can help to improve the delivery of reliable power from utilities. This report summarizes the technical challenges associated with utilizing power electronics devices across the entire spectrum from applications to manufacturing and materials development, and it provides recommendations for research and development (R&D) needs for power electronics systems in which the Department of Energy (DOE) could make a substantial impact toward improving the reliability of the bulk power system.*

***Index Terms—*** *Power Electronics, FACTS, HVDC, Distributed Energy system, Thyristor.*

### I. INTRODUCTION

The adoption of renewable energy is being promoted as a measure to help mitigate the problem of global warming. The generated power output from renewable energy, however, is often difficult to control, and if adopted in large quantities, may cause frequency fluctuations throughout the entire power system and local voltage fluctuations may occur. A smart grid is a system that reduces the effect on the entire power system from the mass adoption of renewable energy, and ensures a stable supply of electrical power. By simultaneously controlling the generation, distribution and consumption of energy, the efficient use of energy can be achieved. With a smart grid, a compensating high-speed high-accuracy power supply system must be used to connect renewable energy, for which the generated output power is difficult to control, to the power system, and power electronics technology plays an important role in the realization of such a system. In particular, many types of distributed power sources generate DC power, and power electronics technology for performing power conversion is one of the most important technologies for smart grids. This paper discusses the role, functions and devices of power electronics required in smart grids, and also describes application examples and initiatives for the future.

### II. NEED OF POWER ELECTRONICS IN POWER SYSTEM

The applications of PCSs are found in many forms within the power system. These range from high-voltage direct current (HVDC) converter stations to the flexible ac transmission system (FACTS) devices that are used to control and regulate ac power grids, to variable-speed drives for motors, interfaces with storage devices of several types, interfacing of distributed energy resources (DER) with the grid, electric drives in transportation systems, fault current–limiting devices, solid-state distribution transformers, and transfer switches. Presently, approximately 30% of all electric power generated utilizes power electronics somewhere between the point of generation and its end use. Most power electronics uses today are for improved control of loads such as variable-speed drives for motors that drive fans, pumps, and compressors or in switching power supplies found throughout most consumer products. By 2030, it is expected that perhaps as much as 80% of all electric power will use power electronics somewhere between generation and consumption, with the greatest gains being made in variable speed drives for medium-voltage (4.16 to 15 kV) motors, utility applications such as FACTS or high-voltage HVDC converter stations, or in the interface required between utilities and DER such as micro-turbines, fuel cells, wind, solar cells, or energy storage devices. Electric power production in the 21st century will see dramatic changes in both the physical infrastructure and the control and information architecture. A shift will take place from a relatively few large, concentrated generation centers and the transmission of electricity over mostly a high-voltage ac grid to a more diverse and dispersed generation infrastructure. The advent of high-power electronic modules will continue to encourage the use of more dc transmission and make the prospects for interfacing dc power sources such as fuel cells and photovoltaic more easily achievable.

## B. *Utility Application of Power Electronics*

Recently, power electronics products incorporating the above technologies have become possible to manufacture, and the applicable range of power electronics technology has expanded. Additionally, complex control has become easier to implement in the distribution of energy, enabling more efficient utilization of the public infrastructure. Figure 1 shows a conceptual diagram of a smart power distribution supply chain in a smart grid. In Fig. 1, sensors and smart meters monitor the system information, and power generation, distribution and consumption are optimized so that the system will operate more efficiently. High-power electronic devices will play an important role in improving grid reliability, including use in energy storage systems, FACTS applications, distributed energy (DE), and HVDC. This report breaks down the applications into two main sections:

- Power Generation
- Transmission and distribution applications of FACTS and HVDC
- DE interfaces

# III. *POWER GENERATION*

The power stabilizer is introduced below as an example application of power electronics for power generation. The generators in a power system are mainly rotary-type generators, and this is essentially the same for smart grids as well. As described above, however, when generating equipment that uses renewable energy is introduced in large amounts to a power system, the frequency control of the system will be affected due to the instability of the power generation. By using a power storage device to compensate for the power generation instability and by implementing control so that the output of the generating equipment is stable, stable power can be supplied to the system. Figure 2 shows the configuration of this power stabilizer. Figure 2 shows the case of wind power generation, but the same configuration could also be used for photovoltaic power generation. Power stabilizers charge and discharge storage cells so as to compensate for the corresponding output fluctuation of renewable energy, thereby smoothing the combined outputs at points of interconnection with the power system. Charging and discharging can be performed according to bidirectional inverter control. The purpose of smoothing is to stabilize the power system voltage and frequency. To stabilize the voltage, active power control and reactive power control are performed. To stabilize the frequency, governor free (GF) control for short- duration fluctuations, load frequency control (LFC) for long-duration fluctuations, economic load dispatching control (EDC) for long period fluctuations, and the like are performed. Each control method requires a different power storage capacity. Battery capacity has a significant impact on facility costs, and therefore, the smallest possible capacity is desired.

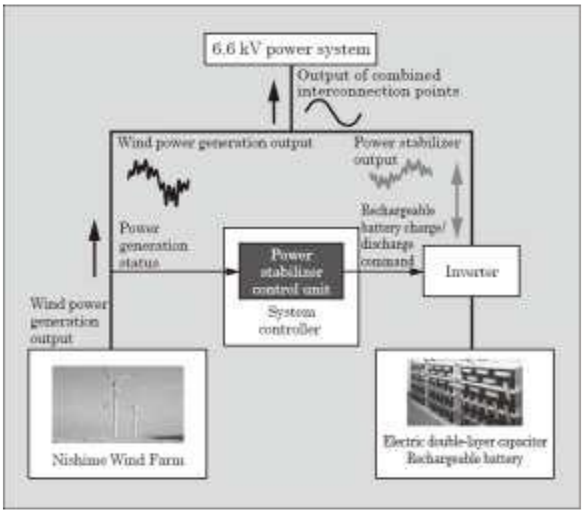


Fig. 2. *Overview of power stabilizer*

# IV. *FACTS: BUILDING TOMORROW'S GRID WITHIN TODAY'S FOOTPRINT*

Now, more than ever, advanced technologies are paramount for the reliable and secure operation of power systems. Yet to achieve both operational reliability and financial profitability, it has become clear that more efficient utilization and control of the existing transmission system infrastructure are required. The challenge facing the power system engineer today is to use existing transmission facilities more effectively. Certainly great difficulty is encountered when seeking permission to construct new transmission lines. Equally certain, the loading required on the system is likely to increase as demand increases. Improved utilization of the existing power system is provided through the application of advanced control technologies. Power electronics– based equipment, or FACTS, can provide technical solutions to address operating challenges being presented today.

A FACTS uses a power electronic–based device for the control of voltages and/or currents in ac transmission systems to enhance controllability and increase power transfer capability. It is an engineered system of advanced power semiconductor-based converters, information and control technologies (software), and interconnecting conventional equipment that builds intelligence into the grid by providing enhanced- power system performance, optimization, and control [2]. Compared with the construction of new transmission lines, FACTS require minimal infrastructure investment, environmental impact, and implementation time. Different types of FACTS technologies.

The many control technic that FACTS technologies that are used are:

- Static Synchronous Series Controller (SSSC)
- Unified Power Flow Controller
- Interline Power Flow Controller
- Phase Angle Regulator
- Convertible Static Compensator (CSC)
- Reactive Power Compensation Sources, e.t.c.

## V. *HIGH-VOLTAGE DIRECT-CURRENT*

The development of HVDC technology started in the late 1920s, and only after some 25 years of extensive development and pioneering work was the first commercially operating scheme commissioned in 1954. This was a link between the Swedish mainland and the island of Gotland in the Baltic Sea. The power rating was 20 MW, and the transmission voltage 100 kV. At that time, mercury arc valves were used for the conversion between ac and dc, and the control equipment used vacuum tubes.

A significant improvement of the HVDC technology came around 1970 when power electronic–based valves using thyristors were introduced in place of the mercury arc valves. This reduced the size and complexity of HVDC converter stations substantially. In 1995 ASEA Brown Bover (ABB) announced a new generation of HVDC converter stations, HVDC 2000, that further improves the performance of HVDC transmissions; and in 1997, a new dc cable technology built upon an IGBT-based voltage- source converter (VSC) called HVDC Light was introduced by ABB. HVDC Light uses new cable and converter technologies (transistors instead of thyristors) and is more economical at lower power levels than traditional HVDC. It is particularly suitable for small-scale power generation/transmission applications and extends the economical power range of HVDC transmission down to just a few tens of megawatts. Recently Siemens has also offered the HVDC Plus technology, its counterpart to ABB's HVDC Light technology.

The layout of a typical HVDC converter station for 500–600 MW is shown in Fig 8. Essentially, the voltage source converter back-to- back (VSC-B2B) system is the B2B configuration of STATCOM units, with a common dc source acting as the dc link to the system. This configuration allows for the control of real power flow across the tie as well as independent dynamic reactive power compensation and continuous voltage control on both sides of the link. This means that the installation is an alternative to conventional HVDC valve systems for linking two networks. Utilizing VSC-based technology also leads to more compact designs and significant space savings compared to classic dc technology. With the ability to parallel multiple terminals on either side of the link, VSC-B2B provides both application flexibility and future expansion capability for large amounts of dc-tie control across ac networks.

In short, this B2B configuration to create a dc link represents an important potential FACTS configuration for HVDC-type operation, but with superior performance and control advantages as compared to conventional HVDC technology. Deploying VSC units in the B2B configuration offers another approach for interconnecting large network areas that are asynchronous, have weak short-circuit capacity, or are limited by some other system constraint. This would allow for "seamless" interconnection of proposed regional transmission organization (RTO) areas, more dynamic control for future East-West ties, as well as ties to Canada and Mexico, and can also provide inter-tie reliability improvements and power flow control.

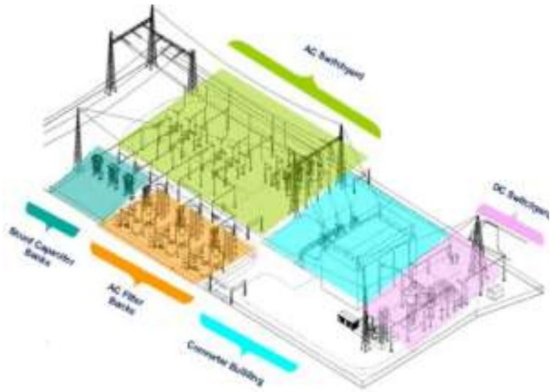


Fig. 8. *Layout of a typical HVDC converter statio*

## VI. *Power Electronics Interface For Distributed Energy System*

Distributed generation (DG) applications today are primarily for niche markets where additional power quality is desired or local onsite generation is desired. In some cases, the distributed energy resource (DER) is designated for backup and peak power shaving conditions. Frequently, these generators are in an inoperative state for long periods until the needs of the load or the local utility require additional generation. Thus, DG can be costly to install, maintain, and operate for most commercial customers. There are several contributing factors to high costs, including the high cost of natural gas, lack of a standard installation process, additional overcurrent and overvoltage protection hardware required by the utility, and the capital cost of any of the new technologies such as microturbines, which is double the cost of conventional diesel power gensets. DE is cost-effective in some niche markets where the electricity cost is extremely high, such as Hawaii and the Northeast, or where outage costs are costly. Two directions for achieving cost- effectiveness for DER are reducing the capital and installation costs of the systems and taking advantage of additional ancillary services that DE is capable of providing. A market for unbundled services (ancillary services) would promote installations of DG where costs could not be justified based purely on real power generation. Power electronics currently are used to interface certain DER such as fuel cells, solar cells, and microturbines to the electric power grid to convert high-frequency ac or dc voltage supplied by the DE source to the required 50-Hz ac voltage of the grid [1, 2]. However, power electronics also offer significant potential to improve the local voltage regulation of the grid that will benefit both the utility and the customer-owned DE source. Basically, power electronics for DER are in their infancy. Power electronics offer the conversion of real power to match the system voltage and frequency, but this interface could do much more. For example, the power electronics could be designed to produce reactive power by varying the phase shift in the voltage and current waveforms from the power electronics. Also, various controls could be built into the power electronics so the DE can respond to special events or coordinate its operation with other DE sources on the distribution system.

The goal ultimately is to achieve a "plug and play" connection of DER with the electric power grid. Some of the objectives are

1. "Good citizen" operation: DER do not impact other devices or loads on the electric grid in a negative way—they only help the grid.
2. Fault contribution suppression: Fast power electronics can respond to fault events on the electric grid and shut down the power feed from the DER.
3. Standard connection scheme: Standardization of power electronics interfaces offers the ability to standardize the connection of DER.
4. Smart controls: The combination of controls with the power electronics offers the ability to optimize local control of DER as well as achieve ancillary services for the grid, such as voltage support.
5. Event response: The combination of communications with the controls and power electronics could enable DER to be responsive to the needs of the power grid. The DER could pick up additional load to reduce power capacity demands or could inject power into the grid to offset generation and transmission shortfalls.

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