Potential improvement

Transmission technologies to support the integration of renewable energy

ROLF GRUNBAUM, SIMON VOGELSANGER, ANDERS GUSTAFSSON, JANISSA AREVALO – In recent years, high-voltage transmission networks have been presented with unprecedented challenges. These stem largely from deregulation, a rapid increase in inter-utility power transfers and impediments to building new transmission systems due to economic and environmental constraints. Added to this is the difficulty of controlling the flow of power and maintaining stability, especially when integrating very large amounts of renewable energy (RE) – from remote, offshore wind farms, for example – into the grid. Periods of strong wind or high solar radiation and low load can exacerbate problems. These challenges can be addressed by products such as ABB's FACTS (flexible alternating current transmission systems) and HVDC (high-voltage direct current) technologies, which allow more power to be transferred in a very flexible, controllable and stable way.

1 Asmunti 400 kV series capacitor, Finland

In theory, limitations on power transfer capacity or power flow control can always be circumvented by adding new transmission and/or generation facilities. ABB's FACTS devices help to achieve the same goals without such major system additions – and HVDC technology is the ideal complement to cope with even more demanding power transmission tasks.

A FACTS solution is justified when rapid response, frequent output variations or a smoothly adjustable output is required. The main devices in the FACTS family are:
- The static var compensator (SVC)
- Series capacitors (SCs)
- The STATCOM (static compensator) devices SVC Light® and PCS 6000

The static var compensator

An SVC can rapidly regulate line voltage and bring it to the required set point. Following a power system incident – eg, a network short circuit, or line or generator disconnection – the SVC will supply dynamic, fast-response reactive power. In addition, an SVC can also increase transfer capability, reduce losses, mitigate active power oscillations and prevent overvoltages at loss of load. The fast var capabilities of an SVC make it suitable for:
- Steady-state and dynamic voltage control to give increased power transmission and reduced voltage variations.
- Synchronous stability improvement to bring increased angular stability and improved power oscillation damping.
- Power quality improvement in grids feeding heavy industrial loads.

ABB recently implemented two SVCs – each rated at ± 250 MVAr – in the Norwegian 420/300 kV power transmission network. These were installed at Viklandet and Tunnsjødal substations to increase power import capacity into the region by up to 400 MW.

Series capacitors

Series compensation of power transmission circuits by capacitors has several benefits:
- An increase of active power transmission, without violating angular or voltage stability
- An increase of angular and voltage stability for a given level of power transmission
- A reduction of transmission losses in many cases
- A reduction in the number of transmission lines required

Series compensation requires control, protection and supervision to enable it to perform as an integrated part of a power system. Also, since the series capacitor is working at the same voltage level as the rest of the system, it needs to be fully insulated from ground potential.

The main protective device in the series capacitor is a varistor – usually of the zinc oxide (ZnO) type – that limits the voltage across the capacitor to safe values and protects against any short-circuit currents. A fast protective device is often used to bypass the series capacitor when the varistor cannot absorb excess fault current.

Fingrid, the Finnish transmission system operator, enlisted ABB to install two such series capacitors (301 and 369 MVAr) to help meet internal transmission demands, improve grid stability and boost the export corridor to Sweden by 200 MW → 1.

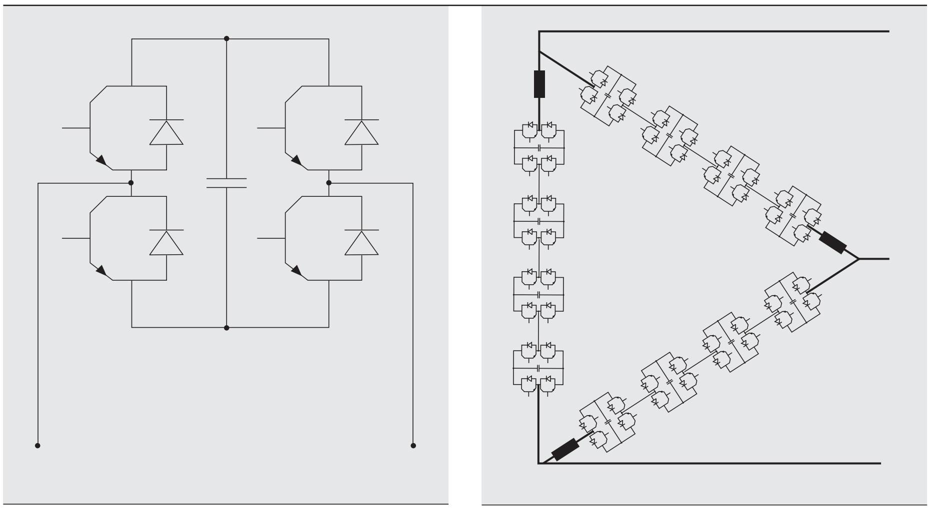
A FACTS solution is justified when rapid response, frequent output variation or a smoothly adjustable output is required.

SVC Light

SVC Light is a STATCOM (static compensator) device based on a chain-link modular multilevel voltage source converter (VSC) concept that is adapted for power system applications. It can deliver

Title picture
How do ABB's FACTS and HVDC technologies allow network operators to increase power transmission levels? Shown is the SVC at the Viklandet 400 kV substation in Norway.

2 Multilevel chain-link converter setup



2a H-bridge cell with IGBTs (one single phase)

2b Three-phase chain-link of H-bridges

3 Modular H-bridge units

reactive power to the grid with a highly dynamic response. SVC Light can, for instance, support weak grids, improve large wind farm availability under varying grid conditions and relieve grids in hot countries that are loaded by a large number of air conditioners.

IGBTs (insulated-gate bipolar transistors) are key components of SVC Light. The multilevel chain-link solution is built up by linking H-bridge modules in series to form one phase leg of the VSC branch ➔ 2.

An SVC can rapidly regulate line voltage and bring it to the required set point.

SVC Light is available for system voltages up to 69 kV and converter ratings up to ± 360 MVAr ➔ 3. For higher voltages, a step-down transformer is used to connect SVC Light to the grid.

To increase the dynamic stability and capacity of their network, Transelec S.A. – Chile's main transmission owner and operator – decided to install SVC Light. The device is rated at 65 MVAr inductive to 140 MVAr capacitive at 220 kV and is located in the heavily loaded Cerro Navia 220 kV substation in Santiago de Chile. As well as increasing the capacity, SVC Light regulates and controls the 220 kV grid voltage under steady-state and contingency conditions, and provides dynamic, fast-response reactive power following system events.

PCS 6000 STATCOM and offshore power transmission

Because the wind out at sea is strong – particularly in the afternoon, when electricity consumption is high – wind farms are increasingly being built offshore.

An offshore wind turbine delivers its power via a platform-based transformer and AC cable to shore, where the voltage is stepped up and the power fed into the grid. The remoteness of the wind generator from the main part of the grid can raise stability and reliability issues, which is why transmission system operators are strengthening grid code requirements – specifically those related to reactive power, voltage control and fault ride-through capability.

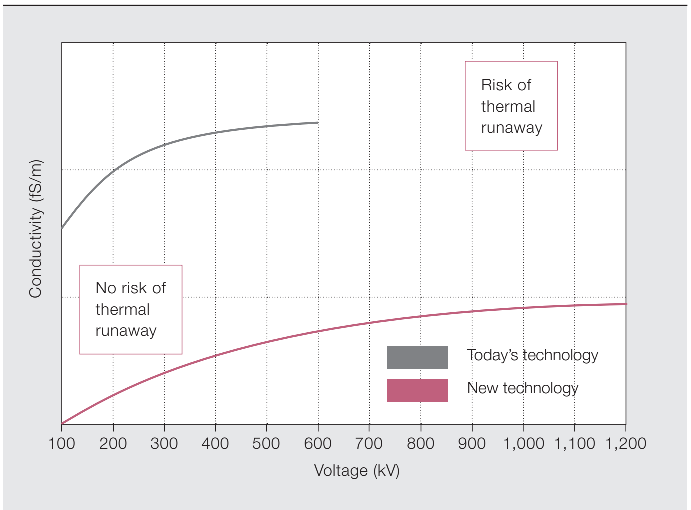
FACTS can provide the fast, dynamic voltage control required by these grid codes, whereas conventional, mechanically switched reactive power components such as capacitor and reactor banks cannot.

On top of the usual grid reactance, wind farm transformers and cables add reactance that varies with active power output. These additional, variable sources of reactive power also need to be compensated for. This can be done by using ABB's PCS 6000 STATCOM.

Series compensation requires control, protection and supervision to enable it to perform as an integrated part of a power system.

4 Type testing of the 525 kV extruded HVDC cable system

5 Comparison of conductivity vs. voltage for the new and previous HVDC cable insulation system



> The PCS 6000 ensures full grid compliance and dynamic power compensation for any wind farm, and is designed as a compact, modular system for applications up to 38 MVAr per unit.

The PCS 6000 ensures full grid compliance and dynamic power compensation for any wind farm. It is designed as a compact, modular system for applications up to 38 MVAr per unit. Higher power requirements can be achieved by simply paralleling multiple PCS 6000s. More than 20 PCS 6000s are already in operation in various wind farms.

SVCs, series capacitors and STATCOM devices enhance AC transmission; ABB's HVDC technology makes DC transmission simpler.

HVDC Light (VSC technology)

Typically, HVDC is a more cost-efficient technology for transmission of large amounts of power over distances exceeding 600 km by overhead lines and about 50 to 100 km in the case of underground or subsea cables. However, many other factors make HVDC technology (particularly VSC-based HVDC such as ABB's HVDC Light) the ideal complement for evolving AC grids. For example, HVDC Light systems enable neutral electromagnetic fields, oil-free cables and compact converter stations. Further, they help manage the increasing challenges of renewable energy integration with rapid control of active and reactive power (independently), the provision of voltage support and improvement in power quality. Other advantages – such as black-start capability and the ability to connect to weak AC grids – make HVDC Light especially attractive for grid interconnections and power provision to isolated systems or crowded metropolitan areas. Strong transmission connections contribute to reduced variability and increased forecast accuracy of renewable generation due to the geographical smoothing effect over large areas.

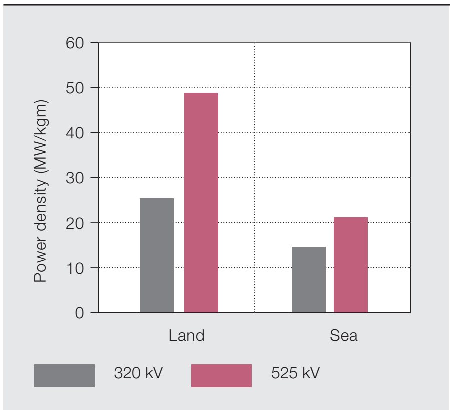
HVDC Light – highest voltage and longest cable

Recently, ABB set an HVDC Light voltage world record with the 500 kV Skagerrak link between Norway and Denmark. ABB has delivered all four of the Skagerrak system's links: Skagerrak 1 and 2 in the 1970s, Skagerrak 3 in 1993 and now Skagerrak 4. The system spans 240 km and provides 1,700 MW of transmission capacity to enable hydrogeneration and reservoir storage in Norway to be used to balance wind generation in Denmark.

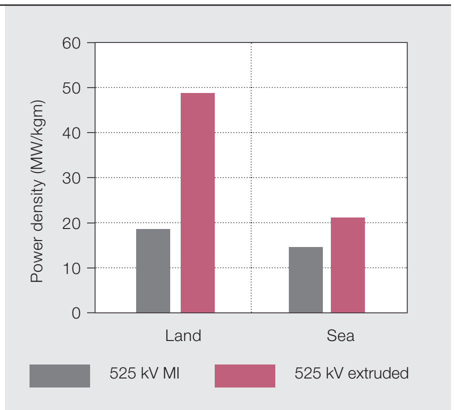
Skagerrak 4 comprises two 700 MW VSC stations. The new link operates in bipolar mode with the Skagerrak 3 link, which uses classic line-commutated converter HVDC technology. This is the first time the two technologies have been connected in such a bipole arrangement. ABB's advanced MACH control system was used to master the different ways power reversal is handled between the two technologies.

ABB will also deliver the world's longest extruded HVDC cable – NordBalt, between Sweden and Lithuania. NordBalt (300 V/700 MW) comprises a pair of cables with a total length of 53 km over land and 400 km under the Baltic Sea. The cable route has to pass through formerly mined areas and explosives dumping grounds, as well as pass through a Natura 2000 nature protection area on

6 525 kV cable system power density comparisons



6a With a 320 kV extruded DC cable system; comparison for 1.5 GW or less (525 kV Al, 320 kV Cu)



6b With MI cable (Al conductors)

the Lithuanian side. The cable strengthens electricity supply and energy security on both sides of the Baltic Sea and integrates the emerging Baltic electricity trading market with the Nordic market.

A new, more powerful cable system

Extruded HVDC cable system technology is appropriate when power needs to be efficiently transported through populated or environmentally sensitive areas, or in coastal and open-sea applications.

ABB developed and successfully tested a 525 kV DC cable system with a power rating well above 2 GW for both subsea and underground applications. This innovative system utilizes a new cross-linked polyethylene (XLPE) DC insulation material, an oil- and porcelain-free termination based on ABB's technology for bushings, a land joint and a flexible sea joint. This new 525 kV HVDC cable system opens up an exciting future for power transmission and is a major step toward a DC grid vision for the integration of energy markets and greater utilization of renewables ➔ 4. A single 525 kV extruded HVDC cable pair – with each cable the diameter of a compact disc – can transmit enough power from large offshore wind farms to supply 2 million households.

HVDC is a more cost-efficient technology for transmission of large amounts of power over long distances.

A good HVDC cable insulation material should have a low DC conductivity to avoid thermal losses. The conductivity of insulation materials increases with the electric field and temperature. Therefore, higher conductivity increases the risk of thermal runaway and electrical failure. ➔ 5 compares the conductivity of the new cables with that of other cables. In the latter, the risk of thermal runaway increases when the type test voltage exceeds 600 kV, in the former, this risk is negligible – even with much higher voltage levels.

The new terminations are based on existing ABB HVDC bushing technology. The polymeric composite insulator used offers maximum safety without the risk of shrapnel from explosions. This safety is provided by elastomer elements (adapters and stress cone) – including a material with highly nonlinear electric properties and geometric elements.

The 525 kV extruded DC cable system can transmit 50 percent more power over extreme distances than previous solutions (eg, the 320 kV extruded DC system). The technology enables the lowest cable weight per installed megawatt of transmission capacity and the higher voltages provide reliable transmission and low energy losses.

Compared with the 320 kV level, the transferred power given as MW/kgm (power per kilogram of one meter cable) is about double that of a land cable circuit and 50 percent more than a submarine circuit ➔ 6a.

When compared with "classic" HVDC cables with their insulation comprising paper impregnated with a highly viscous oil (also called mass-impregnated or MI cables), the extruded DC cable system has an advantage in terms of MW per kg and meter cable ➔ 6b. Also jointing time is significantly shorter for an extruded cable system compared with the MI cable.

The trend toward more and larger renewable energy plants is very clear and very strong. FACTS and HVDC technologies will help support interconnected, flexible and reliable grids. Many innovative and sophisticated products are already available to help overcome the challenges involved with RE integration and enhance the power system flexibility and efficiency required to satisfy the ever-growing need for energy around the world. New possibilities will be opened up by new technologies and products, such as ABB's 500 kV VSC converter stations or the new extruded 525 kV HVDC cable. Advances such as these reflect ABB's commitment to remain leaders in the development and use of power transmission technologies.

Rolf Grunbaum
ABB Power Systems, FACTS
Västerås, Sweden
rolf.grunbaum@se.abb.com

Simon Vogelsanger
ABB Power Systems, FACTS
Turgi, Switzerland
simon.vogelsanger@ch.abb.com

Anders Gustafsson
ABB Power Systems, High Voltage Cables
Karlskrona, Sweden
anders.h.gustafsson@se.abb.com

Janissa Arevalo
ABB Smart Grids Industry Sector Initiative
Zurich, Switzerland
janissa.arevalo@de.abb.com