Sustainable links

HVDC is a key player in the evolution of a smarter grid

RAPHAEL GÖRNER, MIE-LOTTE BOHL – Today's electricity supply depends predominantly on large generating plants such as fossil fuel or nuclear facilities. Traditionally, the control strategy of transmission and distribution network operators builds on the controllable nature of these plants in matching the more inelastic and uncontrollable demand side. Increasing use of renewable energy sources such as wind and solar is changing this strategy. The availability of these new technologies is less controllable and predictable. Grids must hence be able to rapidly, reliably and economically respond to large and unexpected supply-side fluctuations. HVDC technology – in particular HVDC Light® – allows rapid and precise control of voltages and power flows. It is reliable and economical, and can be used to flexibly enhance existing AC grids. HVDC Light is also the first choice for transmitting power from large offshore wind farms to AC grids.

1 Drivers and HVDC applications

Drivers	Applications
Energy efficient bulk power long distance distance transmission	UHVDC, HVDC
Subsea transmission	HVDC, HVDC Light®
Connectiong renewable energy	Remote hydro: HVDC, UHVDC Offshore wind: HVDC Light DC grid (HVDC Light)
Grid reliability	HVDC Light
Difficult to build new transmission	HVDC Light underground transmission Converting AC OHL to DC OHL: HVDC, HVDC Light
Connecting networks Trading	Asynchronous connections HVDC, HVDC Light Back-to-Back

HVDC (High Voltage DC) technology can contribute toward future grids in many ways. These include:
Flexibility: It is well suited for quick responses to both operational changes and customer needs
Accessibility: It is accessible for all power sources, including renewable and local power generation
Reliability: It assures both quality of supply and resilience toward uncertainties and hazards affecting production of renewable energy.
Economy: It provides efficient operation and energy management, and the flexibility to adapt to new regulations.

In technical terms, HVDC technology supports:
- Load flow control
- Reactive power support
- Voltage control
- Power oscillations control
- Flicker compensation
- Voltage quality
- Handling of asymmetrical loads
- Handling of volatile loads

HVDC – a tool kit for smart transmission

ABB's HVDC technologies have been selected for some of the most demanding transmission schemes being realized today. These technologies, HVDC Classic and HVDC Light, are mainly differentiated according to their applications → 1.

HVDC Classic is primarily focused on long-distance, point-to-point bulk power transmission. A typical application can be the transmission of thousands of megawatts from remote hydro sources to load centers: For example the 800 kV Xiangjiaba-Shanghai link, which provides the capacity to transmit 6,400 MW over a distance in excess of 2,000 km. The link has an overall energy efficiency of 93 percent, yet its land use is less than 40 percent of that needed by conventional technology. At more than 99.5 percent, availability is also very high.

HVDC Light, on the other hand, is ideal for integrating dispersed, renewable generation, eg, wind power, into existing AC grids. It is also used for smart transmission and smart grids due to its great flexibility and adaptability.

The first HVDC link in the world to connect an offshore wind farm with an AC grid is the BorWin1 project. Based on HVDC Light technology, this 200 km link connects the Bard Offshore 1 wind farm off Germany's North Sea coast to the HVAC grid on the German mainland. This link transmits 400 MW at a DC voltage of ±150 kV and was ready for service in late 2009.

When complete, the wind farm BARD Offshore 1 will consist of 80 wind generators, each with a capacity of 5 MW. These will each feed their power into a 36 kV AC cable system. This voltage will then be transformed to 155 kV AC before reaching the HVDC Light converter station, located on a dedicated platform → 2. Here the AC is converted to ±150 kV DC and fed into two 125 km sea cables, which then continue into two 75 km land cables, transmitting 400 MW power to the land-based converter station at Diele in Germany.

The 800 kV DC link connecting Xiangjiaba with Shanghai can transmit a power of 6,400 MW over a distance of more than 2,000 km.

HVDC Light technology

HVDC Light is based on voltage source converter (VSC) technology. It uses IGBTs (insulated-gate bipolar transistors) connected in series to reach the desired voltage level. This technology is used for power transmission, reactive power compensation and for harmonics and flicker compensation.

Besides the converter itself, an HVDC Light station comprises AC and DC switchyards, filters and the cooling system. ABB's converter design ensures both steady-state and dynamic operation with extremely low levels of induced ground currents. This is a major advantage in an offshore environment, as it eliminates the need for cathodic protection as part of the installation.

The magnitude and phase of the AC voltage can be freely and rapidly controlled within the system design limits. This allows independent and fast control of both the active and the reactive power, while imposing low harmonic levels (even in weak grids).

Normally, each station controls its reactive power contribution independently of the other station. Active power can be controlled continuously and, if needed, almost instantly switched from "full power export" to "full power import." The active power flow through the HVDC Light system is balanced by one station controlling the DC voltage, while the other adjusts the transmitted power. No telecommunications are needed for power balance control.

From a system point of view, an HVDC Light converter acts as a zero-inertia motor or generator, controlling both active and reactive power. Furthermore, it does not contribute to the grid's short-circuit power as the AC current is controlled by the converter.

Offshore wind integration

An HVDC Light converter station's ability to enforce an AC voltage at any arbitrary value of phase or amplitude is of great value in starting an offshore network. Initially, the offshore converter operates as a generator in frequency-control mode, creating an AC output voltage of the required amplitude and frequency. The voltage is ramped up smoothly to prevent transient overvoltages and inrush currents. Finally, the wind turbine generators are automatically connected to the offshore network as they detect the presence of the correct AC voltage for a given duration. This functionality cannot be realized with classical thyristor-based HVDC transmission, as the latter would require a strong line voltage to commutate against.

2 BorWin alpha, the platform-based HVDC Light converter station

An HVDC Light connection can similarly be used for network restoration after a blackout. As a blackout occurs, the converter will automatically disconnect itself from the grid and continue to operate in "house-load" mode. This is possible because the converter transformer is equipped with a special auxiliary power winding for the supply of the converter station.

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Meeting strict grid codes

With globally installed wind power generation experiencing rapid growth, grid code requirements are becoming stricter. Most present grid codes set requirements on "fault ride through" or "low-voltage ride through," meaning that a wind turbine or park must be able to survive sudden voltage dips down to 15 percent (and in some cases down to zero) of the nominal grid voltage for up to 150 ms.

Often applications expect frequency response requirements (ie, the wind farm power output must rise in response to decreasing grid frequency and vice versa). In a wind farm connected via an HVDC Light transmission system, frequency response control can be implemented via a telecommunications link, which also transmits the momentary main grid frequency as well as other variables. Since the amplitude, frequency and phase of the voltage on the wind farm bus can be fully controlled by the converters, the grid frequency can be "mirrored" to the wind farm grid without any significant delay.

If a reduction in the main grid voltage occurs, power transmission capability is reduced correspondingly due to the current limit of the land-side converter. In a "standard" HVDC Light transmission system connecting two utility grids, a similar scenario is solved by immediately reducing the input power of the rectifying converter through closed-loop current control.

However, a reduction in input power of the offshore converter can cause the wind farm's bus voltage to increase notably, causing the converter and/or the wind turbines to trip. One possible solution is to use the wind farm's grid voltage to reduce generator output immediately.

Due to the link's low DC capacitance value, an interruption of power transmission can cause the DC voltage to rise to an unacceptably high level (such as to the 30 percent overvoltage level tripping limit) in just 5 to 10 ms. The wind turbine generators must be able to detect this condition and reduce their output power within this time frame. As an alternative, a DC chopper can be used to dissipate excess energy that cannot be transmitted by the inverting converter. This approach minimizes the risk of abrupt power changes from the wind turbines, and the disturbances to which they are exposed will be minimized.

Reducing the generator's power output is an effective method, but it is dependent on the response of the generators to voltage variations. A DC chopper, however, offers a more robust solution in that its operation is the same regardless of generator type. Furthermore, an HVDC Light link, combined with a chopper, decouples the wind park grid from the fault and electrical transients that occur in the main grid, thereby reducing the mechanical stresses on the equipment in the wind turbines.

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This innovative HVDC Light solution is being supplied by ABB to the German TSO (Transmission System Operator) Transpower (formerly E.ON Netz) for what will be one of the largest offshore wind farms in the world. It is the first project in which offshore wind power is connected to the main AC grid using HVDC transmission.

HVDC Light technology features very low electromagnetic fields, oil-free cables and compact converter stations. Moreover, it cuts transmission losses by as much as 25 percent compared with traditional technology. This link will make an important contribution to Germany's goal of increasing the share of renewable energies in power generation from its current level of 15 percent to between 25 and 30 percent by 2030.

Building blocks for super grids

One of the key drivers of smart grids is the integration of renewable energy sources, especially offshore wind power, into the current HVAC grids. This has a huge environmental benefit, as it creates an opportunity to replace fossil fuel with renewable energy. Another benefit is that HVDC Light transmission technology is efficient and based on equipment manufactured with nonhazardous materials.

Future grids, combined with an efficient regulatory framework, will offer electricity customers more choices, increase competition between different providers and encourage innovative technology. As grids get smarter, availability and quality of power supply can be controlled in a much more efficient way supporting today's AC grids.

The recent HVDC Light project BorWin1 is an excellent example of a building block of the future grid. The combination of such offshore wind grid connections with interconnections for electricity trading between neighboring countries will also facilitate the development of so-called super grids. These overlaying DC grids, located either offshore or on land, will be able to feed large power volumes into existing AC grids.

As another example, the East-West Interconnector, a 500 MW, 200 kV transmission system connects the Irish and British HVAC grids. The distance between the respective converter stations is 250 km, with most of it covered by a 186 km sea cable under the Irish Sea, and the rest with short land cables. This transmission will be based on HVDC Light, and will become operational in 2012.

The effect of these building blocks in shaping the evolution of super grids is similar to the historic development of HVAC grids. A century ago, interconnections permitted local generation units and transmission lines to be combined into local grids, which in turn evolved as regional grids. Besides being more flexible and smarter, future grids will also be more reliable and efficient and offer a higher degree of control over generation, integration, consumption, grid voltages and power flows. HVDC will be a dominant enabling technology in realizing this vision.

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