AC/DC

Backing up AC grids with DC technology

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As the demand for energy grows, so too does the demand for reliable supplies of energy. When power grids were established, AC transmission was the preferred choice, overcoming DC's inability to be quickly interrupted and transformed. Now, more intelligent, better-controlled networks are needed. How can these be created? The key lies in combining existing AC and DC technologies, making use of the best of both. HVDC (high-voltage direct current) transmission will be embedded inside the AC grid and will reinforce the operation of the whole grid with its controllability, speed and low losses. At designated locations the HVDC system will operate as a "firewall," supporting the AC system during disturbances.

HVDC transmission is starting to evolve into a grid of its own where very fast HVDC breakers help maintain high availability of the meshed HVDC grid. The existing AC system is utilized to transform power between different voltage levels and to use the less costly AC breaker for local fault clearance, minimizing the impact of an electrical fault.

Reinforcing the AC grid

The existing point-to-point HVDC links already show many examples of support functions, which can, even today, become part of a wider HVDC grid [1]. These support functions address four main constraints in the AC system:

– There must be a power balance between production and consumption (including losses).
– Thermal overloading of the circuits must be avoided.
– The synchronous generators must be in synchronism. If they are not, there may be difficulty maintaining the integrity of the AC system after an electrical fault or avoiding oscillations between the generators.
– Availability of local reactive power control must be ensured. Losing this control may result in a voltage instability, which could spread and endanger the whole power network.

There are also different ways in which AC and DC systems can be connected. The HVDC system can be embedded in the AC system or it can connect separate AC systems → 1 – 2. In the embedded HVDC grid, the AC frequency is the same in all HVDC stations. A power imbalance in the AC grid cannot be alleviated by HVDC control since both ends of the HVDC link are in the same grid. With DC and AC grids in parallel, the AC frequency is the same in the HVDC stations, but the HVDC system is in a strong position to mitigate an existing bottleneck on the AC side. With separated AC grids, the AC frequency differs between the HVDC stations; a power imbalance in one of the AC grids can be alleviated by applying proper HVDC control. The size of the HVDC support can easily be limited to the present capacity (spinning reserve) of the other AC grid.

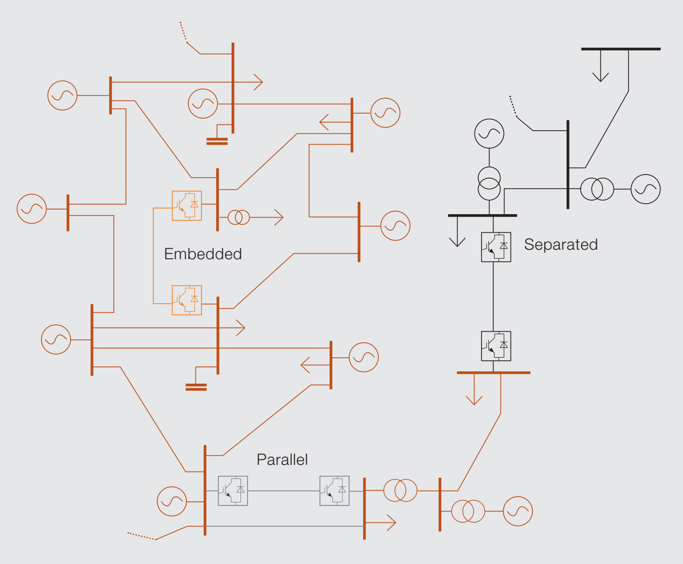
HVDC as a firewall in the AC grid

An HVDC system can be placed between AC grids as a firewall to prevent disturbances spreading from one AC grid to another. The HVDC system can be set up such that loop flows are avoided and market power exchange can be fulfilled. Should a power imbalance occur on the AC side, HVDC control can mitigate the imbalance and borrow spinning reserve from the neighboring AC systems in a controlled manner.

Frequency stability

An imbalance between the produced and consumed power will show up as a frequency deviation. Many HVDC systems can mitigate the frequency devia-

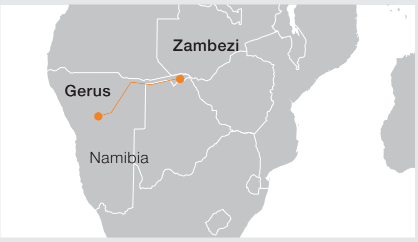
1 Connecting AC and DC systems



2 Level of support possible from an embedded HVDC system during disturbances

	Embedded HVDC grid		Separated AC grids	
	VSC	Classic	VSC	Classic
Operate as a firewall during contingencies	+	0	+++	++
Maintain frequency stability	N/A	N/A	+++	+++
Artificial inertia	N/A	N/A	+++	+
Maintain synchronism	++	+	+	+
Improve voltage stability	+++	+	++	+
Improve power oscillation damping	++	+	++	+
Merchant links	++	++	+++	+++
Black start	+	0	+++	0

3 Case study: Caprivi Link



The Caprivi Link interconnects the Namibian and Zambian/Zimbabwean AC systems → 4. The overhead HVDC line has a length of 952 km. The first stage of the project was a monopole scheme with a nominal power of 300 MW and nominal DC voltage of -350 kV DC.

At the initial stage, the AC networks at both sides are extremely weak and the short-circuit ratio (SCR) at the connection points may be below 0.8. Normally, the AC networks at both sides of the HVDC link are connected to the AC grid of South Africa, resembling a parallel AC structure as in → 1. However, if an AC line is lost it can lead to an islanded network situation in either end of the HVDC link.

For islanded network situations, the converter station has a characteristic comparable to an infinite AC source, ie, a slack bus. The link automatically converts the active power needed to maintain the power balance of the system. It also automatically converts the reactive power needed to keep the AC voltage at the desired level. Under normal AC network conditions, the converter resembles an electrical machine to generate or consume active and reactive power.

Performance under islanded AC network in Namibia

On June 3, 2010, a high-power transmission was planned from Namibia to Zambia. During the process of ramping up power, when the power exported from Namibia was about 80 MW, an overload protection tripped a 220 kV line in Nampower's 220 kV bus zone, which led to an islanded condition in Namibia.

This unplanned event was observed and automatically recorded in both converter stations → 5. The Gerus substation (shown on page 33 of this issue of *ABB Review*) immediately reduced the power to almost zero (see the lower plot in → 5a). About 1 s after the line tripped, the Namibian grid restored stable AC voltage and frequency [2].

tion if one of the converters is connected to a separate AC grid. Assuming that the separate AC grid has spinning reserve available, the stressed grid can be automatically supported to restore frequency stability.

Artificial inertia

In very weak AC systems, frequency variations may be a problem due to the low ratio of rotating mass (inertia) related to synchronous machines. An HVDC link in such an AC system can be controlled to provide additional inertia in order to strengthen the local stability. Such functionality has been implemented in the Caprivi Link project in southern Africa → 3.

Maintaining synchronization

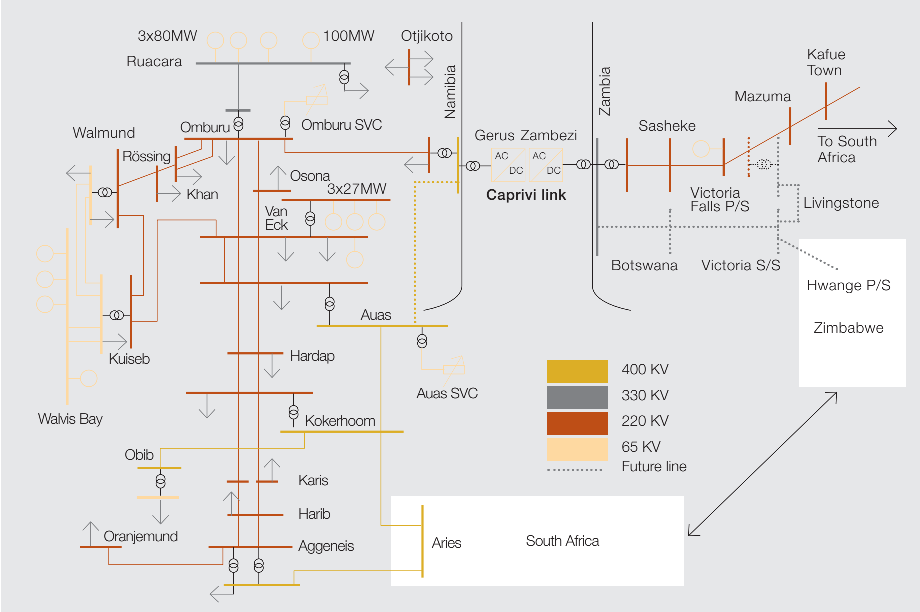
To maintain synchronization, the HVDC system will support the AC system in several ways. For example, during a fault, the VSC (voltage source converter) technology will start to back up the AC system. When the fault is cleared, the reactive power output from the HVDC system will support the power transfer in the AC grid. This will reduce the risk of falling out of step and losing synchronization. Special schemes can be set up in the HVDC system to help quickly restore a viable power flow after a fault.

It is also possible to control the HVDC system in such a way that inadvertent power flow changes in the AC grid are automatically compensated for so that a safe power transfer can be maintained in the AC system. The active power control can, alternatively, be set up such that it resembles the phase-angle dependency of an AC line (possibly with reactive power support at each end).

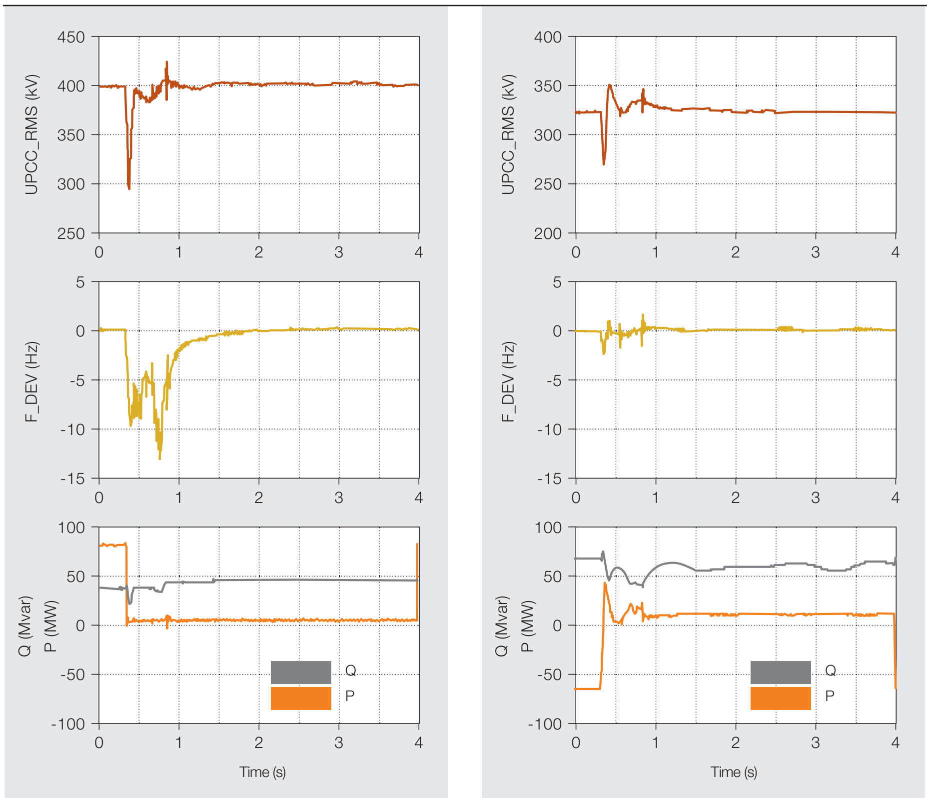
Power oscillation damping

A stressed AC system is prone to electromechanical oscillations of the rotors in the synchronous machines. This is an unwanted situation since it wears down the governor systems of the turbines and indicates an operating working point close to the stability limit related to maximum power transfer. By modulating a control signal to the HVDC system, oscillations can be damped and a safe power transfer limit can be maintained in the AC system. This damping functionality has been implemented in several links, including the Pacific DC Intertie and the Fenno-Skan link.

4 Network map of the Caprivi Link project



5 AC voltage, frequency and converter P/Q loadings for Zambezi and Gerus



5a Gerus

5b Zambezi

Black start

In some AC grids, black-start functionality is very valuable. The restoration process (black start) of an AC system following a contingency related to loss of crucial AC lines, islanding or blackout has some critical requirements, which, in certain cases, can be fulfilled with an HVDC link. VSC transmission technology is particularly suitable. The VSC link can follow the cold load pickup and the pickup of the power production with its smooth control of both active and reactive power. As the AC grid is rather weak and often has reduced short-circuit power during a black start, high requirements are put on reactive power control to maintain voltages. ABB has implemented and tested this for the Estlink 1 project.

Merchant links

The coupling of electricity markets and growing commercial interconnections requires precise, controllable power flows in order to operate effectively in line with the market-derived schedules. Power scheduling on an hour or minute basis is a common situation. The controllability of active power flow in the HVDC system compensates for the power flow in the AC system that would follow the physical laws rather than the prearranged commercial deals.

AC/DC: the grid of the future

The HVDC system will alleviate power imbalances in the AC system and give operators full control over the power flow. With the introduction of VSC technology, HVDC is also able to operate as a FACTS[1] device. The HVDC system can consist of a back-to-back converter, a point-to-point connection, a multi-terminal connection, or a meshed HVDC grid with parallel paths enhancing the availability of the HVDC system.

For more information, please visit
www.abb.com/hvdc

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References

[1] S. G. Johansson, *et al.*, "Power System Stability Benefits with Vsc Dc-Transmission Systems," CIGRE, Paris, 2004.

[2] Y. Jiang-Häfner, M. Manchen, "Stability Enhancement and Blackout Prevention by VSC Based HVDC," CIGRE, Bologna, 2011.

Footnote

1 FACTS, or flexible alternating current transmission systems, are technologies that enhance the security, capacity and flexibility of power transmission networks.