The balance of power

Advanced transmission grids are embedding HVDC Light®

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Have you ever wondered how tightrope walkers manage to maintain their balance on such a narrow cable? These artists must not only maintain their own equilibrium, but must also take into account that their motions cause the line on which they are standing to move. One way to deal with this challenge is to move very slowly so that oscillations never surpass a critical level. A more advanced approach would involve the acrobat actually taking these movements into account and using or counteracting them, so keeping them under control while permitting more and faster activity. The more flexibile reactions of the acrobat permit a fuller use of the system‘s overall dynamics.

On first sight, this may not appear to have much in common with operating a grid. Grids, however, can also have significant stability problems. The traditional remedy, has been to keep loadings below set levels to avoid any risk of instability. Liberalization of electricity markets and the growth of renewable sources are leading to more long-distance transmission and are requiring enhanced network controllability. With HVDC Light®, ABB has introduced a technology that can not only improve transmission capability, but can also actively damp oscillations and enhance stability.

Transmission and distribution

Traditionally, most grids were structured to deliver power from generation plants to customers in the vicinity. Power plants are thus often located around major cities, with the grid infrastructure closely reflecting this match. Today, more and more power is being generated further afield and transmitted over longer distances. This change is driven by multiple demands: One of these is the growing usage of renewable energy, which is often generated in remote locations. Another is the increasing liberalization of power markets, favoring use of generation facilities with the lowest incremental costs. High-voltage grids are thus more and more handling long-distance transmission, and operators are seeking ways to reduce obstacles to the remote sourcing power.

With high-voltage grids increasingly being used in a way for which they were not initially designed, some corridors are having to carry more power and are being operated closer to their limits than ever before. In the case of energy from renewable sources, the challenge is compounded by the intermittent and to some extent unpredictable nature of the supply. New technologies are thus being sought to support these demands while maintaining controllability and stability.

This means that the grid's "natural" power flow, as governed by physical laws, is increasingly being biased by economical driving forces. Besides reliability criteria, the development of future transmission infrastructure must also take into account environmental constraints and energy-efficiency requirements.

The embedding of advanced HVDC Light systems in regional transmission networks is opening up new possibilities to enhance smart grid operations as the deployment of such solutions improves security and efficiency through its inherent controllability.

Infrastructure at its limits

On account of growing congestion, transmission grids are not always able to adequately facilitate the economic exchange of power between adjacent energy markets or enable the optimal use of generation resources. Congestion occurs when actual or scheduled power flows across critical transmission corridors are restricted below desired levels, either by physical capacity or by security restrictions. When such constraints limit the delivery of power from the most desirable generation sources to the load centers, grid operators must use more expensive or less efficient sources of generation.

Furthermore, electric power grids are more and more integrating large-scale sources of renewable energy. The increased use of such intermittent sources, combined with the weak system interconnections in the areas where this generation is typically located, presents new challenges to managing the security of the power grid. With several gigawatts of offshore wind farms now in the advanced stages of planning, particularly in Europe, there is a need for reliable and robust power transmission to shore. In the United States, transmission has also been recognized as the largest single barrier to a significant expansion of wind energy and to achieving the target of it satisfying 20 percent of the nation's electricity supply by 2025 1. Thus, upgrading a transmission system is a key component of a sustainable energy future.

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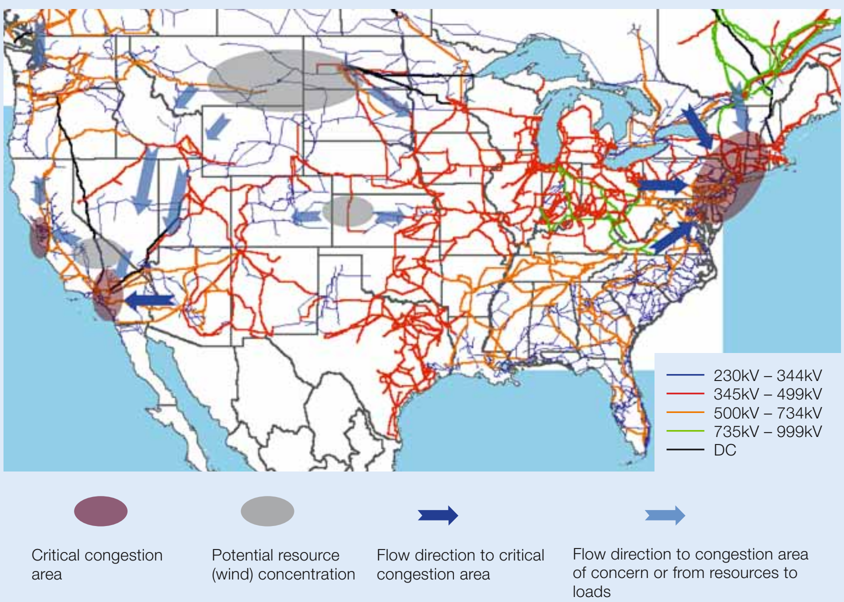
1 In the United States, congestion of transmission lines has been recognized as the largest single barrier to a significant expansion of wind energy.



Source: National Electric Transmission Congestion Study, US DoE 2006

A robust and economical alternative

Incrementing power-delivery capability through the addition of conventional AC lines is increasingly becoming a challenge in meshed, heavily loaded AC grids. Environmental considerations are an important constraint in adding such capacity – often making overhead grid extensions impossible. AC expansion options, both overhead and underground, are furthermore often limited by voltage or transient instability problems, risk of increased short-circuit levels, grid responses and concerns over unacceptable parallel flows in the network. A further aspect is the cost of right-of-way for new transmission in urban areas.

Footnote

[1] HVDC Light® is the ABB product name of an HVDC transmission system using voltage-source converters.

Moreover, there is a high demand for controllable transmission to effectively manage variable flow patterns and accommodate intermittent generation sources 2. Since its introduction in 1997, HVDC Light[1)] is increasingly emerging as an attractive solution to achieve the needed improvement in transmission capacity and the reliable integration of large-scale renewables while satisfying strict environmental and technical requirements.

HVDC Light technology

HVDC Light technology is based on voltage-source converters (VSC) using insulated-gate bipolar transistors (IGBT) [1]. The converters employ high-frequency pulse-width modulation (PWM) switching patterns and can thus control both active and reactive power, rapidly and independently of each other. HVDC Light systems can transmit power underground and under water over long distances. It offers numerous environmental benefits, including "invisible" power lines, neutral or static electromagnetic fields, oil-free cables and compact converter stations. The power ranges of HVDC Light have been improved rapidly 3. In the upper range, the technology now reaches 1,200 MVA for symmetric monopole schemes with cables. The power range can be increased to 2,400 MVA for bipole schemes with overhead lines [2]. One attractive feature of HVDC Light is that the power direction is changed by changing the direction of the current and not by changing the polarity of the DC voltage. This makes it easier to build an HVDC Light system with multiple terminals. These terminals can be connected to different points in the same AC network or to different AC networks. The resulting multi-terminal HVDC Light systems can be radial, ring or meshed topologies 4.

Enhancing smart transmissions

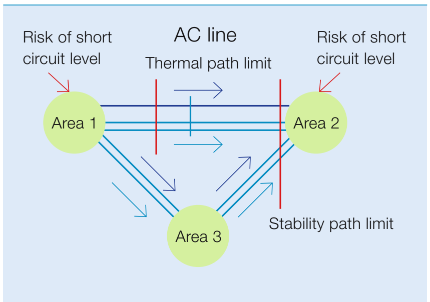
HVDC Light is ideal for embedded applications in meshed AC grids. Its inherent features include flexible control of power-flow and the ability to provide dynamic voltage support to the surrounding AC networks. Together with advanced control strategies, these can greatly enhance smart-transmission operations with improved steady-state and dynamic performance of the grid [3].

Enhancing regional interconnections

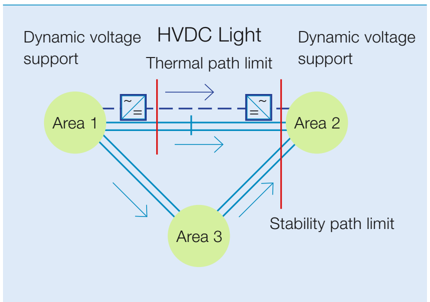
Under normal operating conditions, the power flow of an HVDC Light system can be scheduled on the basis of economic and system-security considerations. Furthermore, DC-link power flows can be dispatched in real time. This high controllability of power flow allows grid operators to utilize more economic and less pollutant generation resources, implement favorable bilateral transactions and execute effective congestion management strategies. Additionally, HVDC Light

2 HVDC Light improves the controllability of grids.

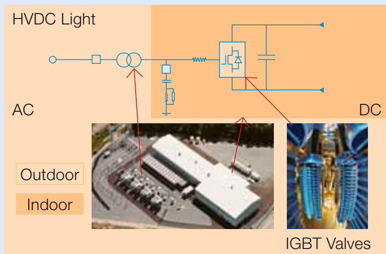
a An additional AC link between Areas 1 and 2 takes some of the strain, but cannot fully relieve the path via Area 3 of its overload.



b The controllability of the HVDC link enables it to carry the desired load and so relieves the other lines.



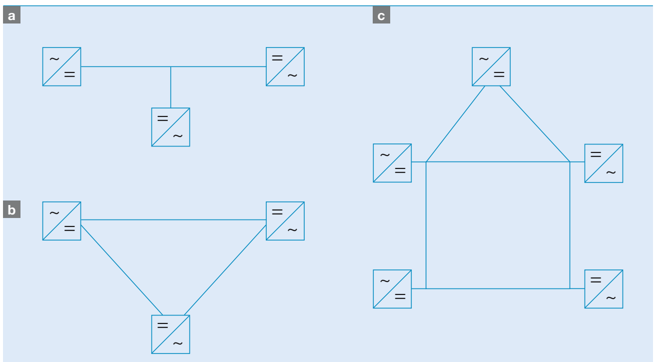
3 HVDC Light converter station and power range for symmetric monopole scheme with cables



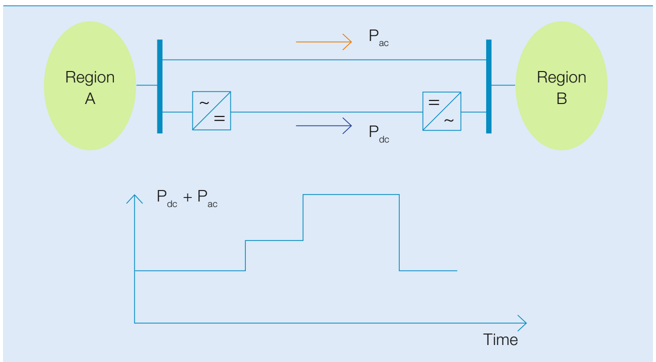
DC Voltage	580 A	1140 A	1740 A
± 80 kV	100 MVA	200 MVA	300 MVA
± 150 kV	190 MVA	370 MVA	540 MVA
± 320 kV	400 MVA	790 MVA	1210 MVA

HVDC Light converter station and power range for symmetric monopole scheme with cables

4 Flexible configuration of multi-terminal HVDC Light systems: radial a, ring b and meshed c.



5 The ability to strictly control power flow in an HVDC Light link means regional power flows can be managed according to contractual agreements, adding stability to the system.

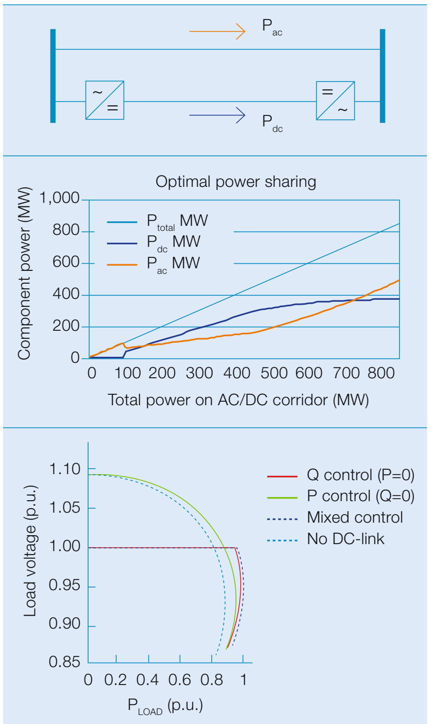


systems can be operated as merchant transmission facilities, similarly to merchant generators. The precise control of power flow through an HVDC Light system according to a contractual agreement simplifies the pricing of power transfers, billing, and preventing undesired flows 5.

Improving overall corridor utilization

In many cases, the capacity of the AC lines that comprise a transmission corridor cannot be fully utilized because of limitations to voltage or transient stability. One great advantage of HVDC Light is that adding such a link in parallel to AC lines can not only increase transfer capability, but it has been shown in studies that this increase can exceed the rating of the HVDC Light system. This gain is due to effective control of damping and dynamic voltage support for the parallel AC lines [4]. In addition, an optimal power-sharing principle can be implemented for a wide range of power-transfer levels to minimize the total energy losses of the hybrid AC/DC corridor. Depending on the operating condition of the hybrid AC/DC corridor, the control priority of the HVDC Light system could change from minimizing loss to maximizing power transfer. This adaptive control strategy can achieve a desirable balance between power transmission efficiency and corridor capacity utilization 6.

6 An HVDC Light link parallel to an AC link can be used to control the resulting hybrid AC/DC corridor, balancing transmission efficiency and corridor capacity utilization.



If a severe disturbance threatens system transit stability, HVDC Light can help maintain synchronized power-grid operation by fast power run-up or run-back control functions.

Integration of offshore wind farms

HVDC Light allows efficient use of long-distance land or submarine cables to integrate large-scale offshore wind farms into utility transmission grids 8. The main features of HVDC Light transmission for offshore wind power evacuation are:

- HVDC Light can fully comply with the grid code.
- Wind turbine generators need no longer be designed to fulfill the grid code. Their optimization can hence focus on cost, efficiency and robustness.
- An HVDC Light system can separate the wind farm from the AC network. Faults in the AC grid will not cause stress or disturbances on wind turbines, and faults in the wind farm will not affect the AC network.
- HVDC Light provides voltage and frequency control, and desired inertia can be emulated to enhance the stability of the AC network.

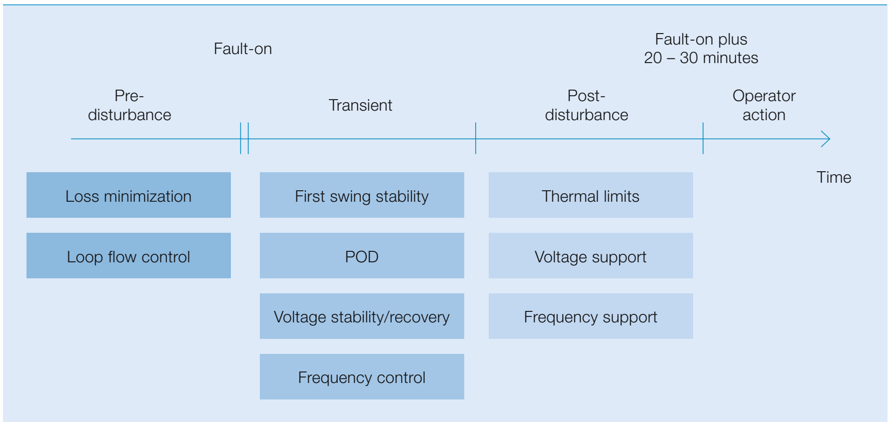
Performance under severe disturbances

Embedded HVDC Light systems can effectively improve the overall performance of the transmission grid during and following severe disturbances. A range of advanced application-control functions can be implemented to address different transient and post-disturbance problems 7.

First-swing stability

If a severe disturbance threatens system transient stability, HVDC Light can help maintain synchronized power-grid operation by fast power run-up or run-back control functions. During the fault phase, sufficient retarding power can be provided through the immediate reversal of HVDC Light power to limit rotor acceleration. Transient stability can also be improved by controlling the HVDC Light converters to provide supplementary reactive and voltage support after fault clearing.

7 Advanced control functions are features of HVDC Light.



8 HVDC Light permits the optimal integration of large-scale offshore wind farms into the grid.

Damping of power oscillations

HVDC Light can provide effective damping to mitigate electromechanical oscillations through the modulation of active and reactive power. A feedback signal such as that from active power flow measurement can be used to drive a supplementary damping control scheme. Alternatively, the SVC-like[2)] characteristic of the converter stations can be used to accomplish damping by injecting modulated voltage signals into the converter voltage control circuit. Logically, both P and Q could be modulated concurrently to achieve a more effective means of damping oscillations. HVDC Light can damp both local and inter-area modes of oscillations 9.

Voltage stability and voltage support

An HVDC Light system can be used to improve voltage stability in a variety of ways. By operating the converter as an SVC or STATCOM[3)] during and after the fault, dynamic voltage stabilization can be enhanced and voltage variations can be minimized. This greatly helps system recovery after a disturbance and reduces impacts on sensitive loads. HVDC Light provides countermeasures for both transient and longer-term voltage instability mechanisms. Fast modulation of reactive power provides dynamic var support for transient voltage stability. In case of longer-term instabilities, in which tap-changers and excitation system responses come into play, HVDC Light can help prevent voltage collapse via gradual P and Q modulation, including reducing active power transfer to increase reactive power capability at the terminal stations 10.

An HVDC Light system can be used to improve voltage stability in a variety of ways.

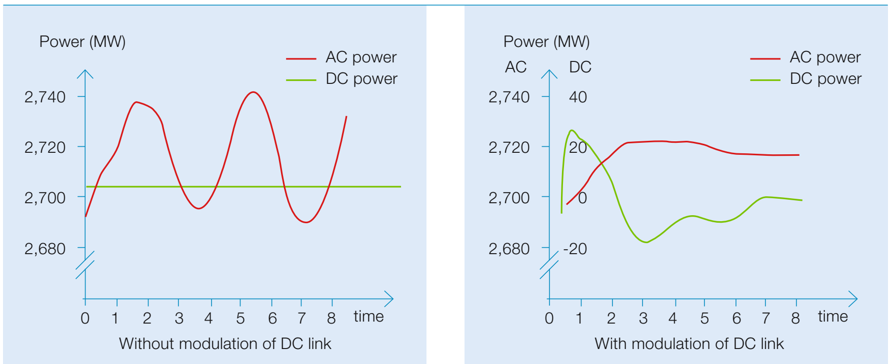
Frequency control and support

If the rectifier and inverter are connected to two unsynchronized power systems, one system can assist the frequency stabilization of the other using modulation functionality. In this control mode, the HVDC Light system adds or subtracts a contribution to the scheduled power order, proportional to the frequency deviation. Similarly, frequency support can be used to speed up restoration of islanded systems following a system breakup. HVDC Light provides the back-up active power required to assist in the frequency control of a neighboring island. At the same time, it acts as an additional load to the other island enabling a timely start up of its generators. HVDC Light frequency control and support can be coordinated with existing under-frequency load shedding schemes to limit frequency decay during a major system disturbance.

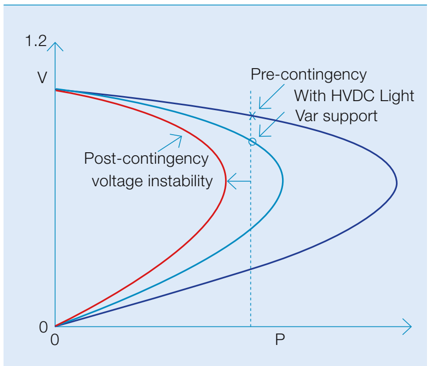
Black-start functionality

HVDC Light can aid in a black start or support restoration of the grid. The main features are a fast startup time, not requiring short-circuit capacity from the grid, the ability to work in pure "SVC-mode" to control voltage, and the ability to support frequency stability during restoration. Typically in a power plant, steam production has to be built up before load is connected to handle the cold-load pickup phenomena[4)]. However, with remotely available power and a dedicated control of HVDC Light, the grid restoration process can be significantly improved and the cold-load pickup phenomenon alleviated 11. Speed and robustness during the buildup are very valuable as the consequences

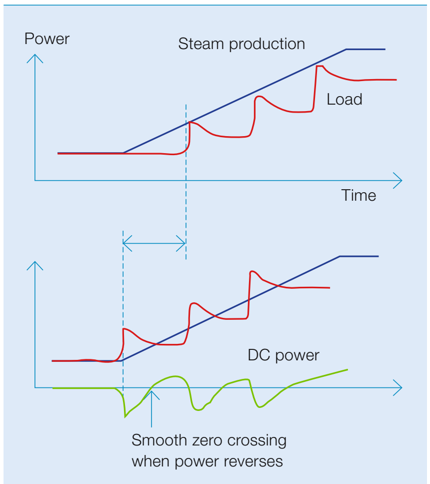
9 HVDC Light can be used to damp power oscillations.



10 HVDC Light's ability to modulate reactive power helps maintain voltage stability after a disturbance.



11 HVDC Light supporting the grid restoration process after a blackout



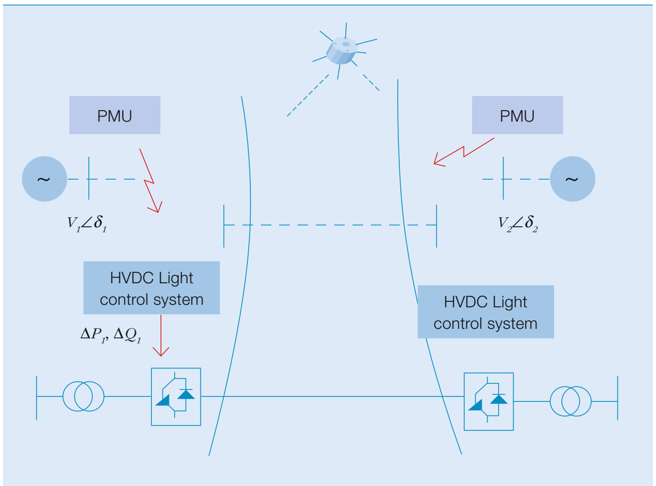
Footnotes

2) SVC: Static var compensator, a device typically made up of thyristor-switched capacitors, thyristor-controlled reactors and harmonic filters and used to inject or absorb reactive power in order to enhance voltage stability.

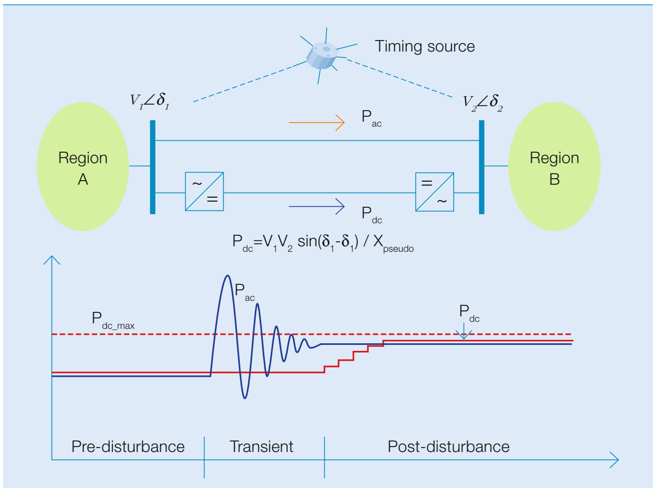
3) STATCOM: Static synchronous compensator, a device similar in function to an SVC but based on voltage source inverters.

4) Cold load pickup is the phenomenon that when bringing back power after an extended outage, the load is often found to be greater than it was before the outage. This can be caused by a combination of equipment-related effects (inrush currents of capacitors, magnetizing currents of transformers etc) and load-related effects such as the re-starting of stalled machinery and processes.

12 In combination with wide-area monitoring and wide-area control system (WAMS/WACS), HVDC Light can further enhance system stability and transmission efficiency.



13 HVDC Light emulating an AC link in a post-disturbance situation. This mode is useful for mitigating possible overloading of adjacent AC lines.



and costs of a blackout increase greatly with its duration.

Further improved performance

Using remote measurements, HVDC Light systems can effectively initiate control individually or cooperatively to improve transfer capability and to counter disturbances such as power oscillations. Such remote power grid information could come from a wide-area monitoring system (WAMS). WAMS, the measurement platform of smart transmission grids, consists of phasor measurement units deployed at geographically disperse locations in the system. GPS time-synchronized measurements of voltage and current phasors together with frequency and binary signals are collected and aligned by a phasor data concentrator. A wide-area control system (WACS) uses these wide-area measurement signals to provide auxiliary controls to power system devices. WAMS/WACS applications range from monitoring (such as state estimation and voltage security monitoring) to wide-area control such as the damping of power oscillations. It is envisioned that the performance of transmission grids can be further improved through the coordinated control of HVDC Light systems enabled by WAMS/WACS 12.

Emulating AC characteristics

In some cases, it is advantageous to use the DC link to emulate AC-line performance with respect to power-flow response to contingencies. The desired AC transmission characteristics allow the DC link to increase power transfer up to its maximum rating or reduce the transmitted power automatically in the post-disturbance period, mitigating possible overloading of adjacent AC lines 13. An embedded HVDC Light system can be autonomously controlled as a pseudo AC-line not requiring frequent schedule decisions from the system operator. This control mode is designed for situations where a centralized dispatch of the HVDC Light link is not a requirement. The set points of the DC link are determined as part of short-range operations planning, which determines the desired strength between the two connection points.

Transmission grid of the future

It is envisioned that the future transmission infrastructure will develop towards a hybrid AC/DC grid structure. In particular, embedded applications of HVDC Light, in combination with wide-area measurement and control systems, are set to significantly improve smart operation of the transmission grid.

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