Impact of HVDC Convertor Technology Choice on Reinforcement within the GB Grid

The National HVDC Centre

BACKGROUND

HVDC 'bootstraps' are becoming a key option in the reinforcement of the transmission system. As the generation mix moves towards renewables, sources are becoming more dispersed[1] and located further from load centres, requiring extensive transmission network upgrades to get the power to where it is needed. As a result of restrictions in space and consenting issues locating new circuits onshore, there has been a move to locate new circuits offshore. This requires long cable circuits, where HVDC technology must be used[2]. This article explores how the choice of HVDC technology can affect the system integration challenge of the required upgrades to the transmission system.

PARALLEL LINKS

There are two embedded HVDC links already in operation on the GB Network (Western Link (LCC) and Caithness-Moray (VSC)), with four more similar links to be delivered in the next decade[4] as shown in Figure 1. Whilst AC network is passive and flows are driven by the relative impedance of the parallel paths, DC links are active elements whose flows are set by controls. Controlling the distribution of power across several embedded HVDC links, makes it possible to manage power flows across constrained circuits or boundaries within the wider AC network actively in real-time. Active Power Oscillation Damping controls on these HVDC links can be used to take advantage of HVDC controlability to limit inter-area oscillation[5]. Both of these capabilities are made possible by separately defined Wide Area Control strategies.[6]

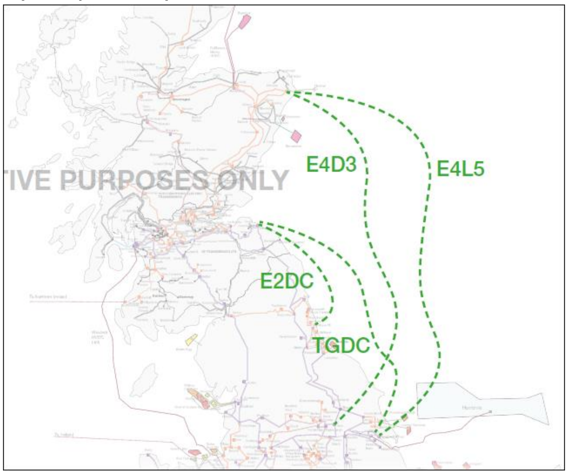

Figure 1 - Map showing four proposed HVDC Links (from [4]).

THE OPTIONS AND THEIR INHERENT IMPACTS ON THE GRID

The two technologies for conversion between AC and DC are Line Commutated Convertor (LCC) and Voltage Source Convertor (VSC). In LCC schemes the electronic valves can be turned on in a controlled manner to achieve desired real power dispatches but require current zero crossings to turn off. This limits the LCC capabilities to respond and support the network in transient timeframes during which the Transmission system voltages are disturbed. LCC solutions require reactive power support around 60% of their active power need at the time and must offset that by banks of capacitors being switched in at appropriate times; no dynamic reactive power can be constructed, so limits in reactive power imbalance must be set by a TO & ESO within which LCC may be operated.

In VSC schemes the electronic valves can be turned both on and off readily allowing control of both real and reactive power. The reactive and active power capability for LCC and VSC converters are illustrated in Figure 2. Because the VSC provides a voltage source in support of the network, it has an inherrent flexibilty to the extent it can track and support the voltage on an onshore transmission system. In practice this is provided such that onshore transmission system does not transiently move too rapidly to track, or the support from the device exceeds its rating. A VSC can also black start an onshore transmission system, requiring no minimum level of system fault level strength to operate, rather more complex controls to support low strength or blackstart conditions. [3]

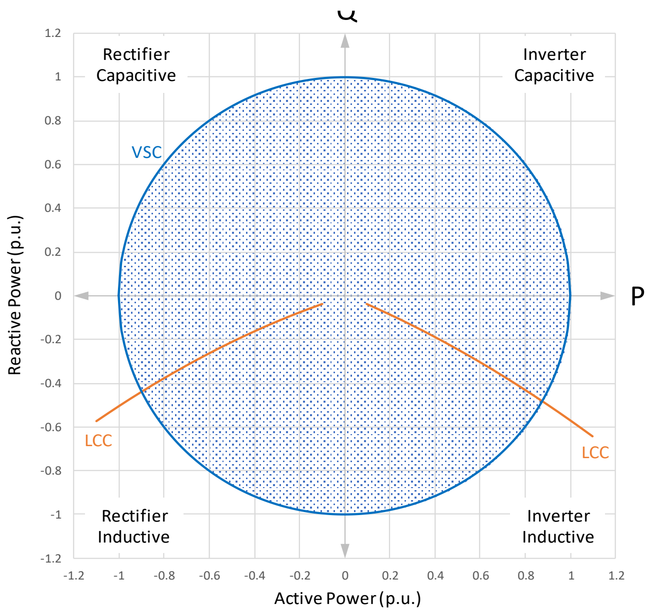

Figure 2 - Active and Reactive power capabilities of LCC and VSC converters.

Both technologies have complex hierachical control structures and associated protections which are normally protectively black-boxed and/or simplified in model exchange to protect IP. This means that for whichever technology selection it is important for a TO and ESO to clearly describe their functional and performance needs of a given HVDC application and ensure appropriate models and relevantly detailed real time models or in most practical cases control and protection replicas are provided, where the considerations of stable network & converter operation and/or protection stability apply.

Authors: Ian Cowan & Ben Marshall
E: info@hvdccentre.com
W: hvdccentre.com

30th November 2021

FLEXIBILITY

VSC is more flexible in its application, including the inherrent ability to affect a near instantenous power reversal as required, ride through and recover from faults, and provide a stabilised onshore system recovery more generally via controlled active and reactive power modulation. These are also key performance needs for a multi-purpose, multi-terminal extension of an initial embedded link- for example for Offshore Wind or in connecting islanded generation and demand to the mainland transmission system[7].

FAULT LEVEL AND NETWORK FAULTS

The fault level is an indication of the relative strength of the network, falling fault levels associated with the shift away from traditional generation sources[9] have a material impact on the control and operability of the network. LCC converters are particularly sensitive to the fault level on the transmission system. Figure 3 shows that LCC links cannot operate at their full capacity at lower fault levels, and cannot be operated at all when the Short Circuit Ratio (SCR) drops below around 2. In contrast VSC links can be used to black start or support the grid even at low fault levels provided their control systems are suitably specified and designed.

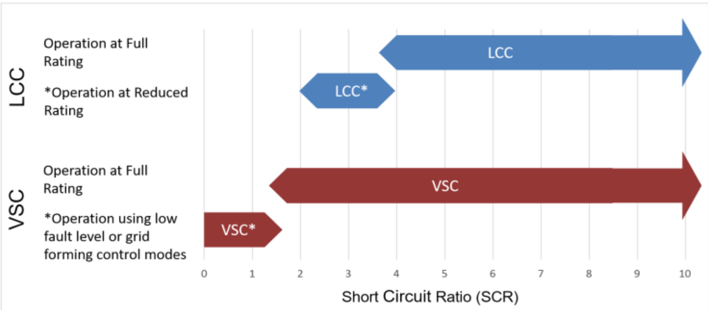

Figure 3 - Typical Stable Short Circuit Ratio (SCR) Ranges of Operation for LCC and VSC HVDC converters.

Faults are an inherrent risk to the tranmission system. However, the SQSS[8] is designed to deal with them in a safe and efficient manner which allows continued operation of the wider system when they occur. Figure 4 shows a potential situation where a significant area of the network sees a low retained voltage during a fault, as the fault level on the transmission system declines, highlighting risk of parrallel HVDC installations disrupted at both ends simultaneously[10].

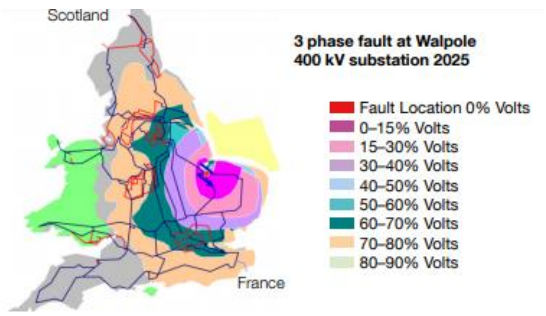

Figure 4 - Map showing effect of reducing fault levels on how voltage dips spread across the Transmission System.

For both technologies the controllers normally used rely on PLLs (Phase Locked Loops) to reference the network across the disturbance, which can have performance issues in low strength networks[11]. An additional issue for LCC schemes is the afforementioned risk of commutation failure which can lead to the convertor having to trip.

Figure 3 shows how HVDC links using each technology embedded within a weak AC network cope with a fault on the surrounding AC network. Figure 5(a) shows the LCC initially transmitting power at a reduced level (0.88pu), as a result of the low system fault level. As the AC circuit fault occurs and is subsequently cleared by protection, and the system fault level reduces further, the LCC link suffers from repeated commutation failure and fails to recover. Protection would then need to operate to trip out the LCC link. In contrast, Figure 5(b), shows the VSC initially transmitting power at its full rating (1pu), unhindered by the low system fault level. As the AC circuit fault occurs and is subsequently cleared by protection, the VSC quickly recovers to transmit power at its full rating again provided it has appropriate tuning and specification.

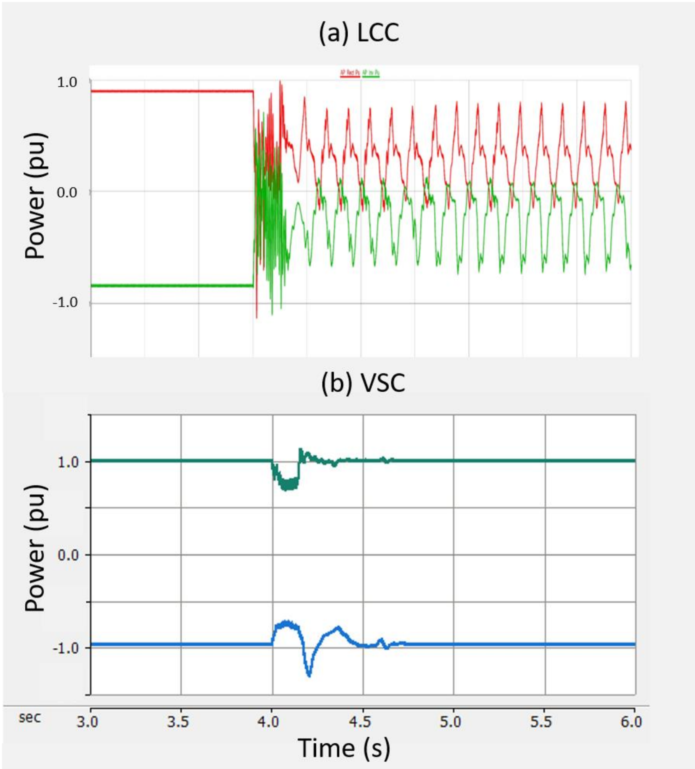

Figure 5 - Plots showing power transfer on HVDC links embedded in very weak AC networks during a 3-phase fault: in (a) above, the LCC-HVDC fails to recover and suffers from repeated commutation failure, whereas in (b) the VCC-HVDC recovers.

This example illustrates that when embedded in weak AC networks, excessive deployment of LCC links may risk exacerbate problems arising from faults in the AC system. VSC links are known to behave more reliably in weak AC networks, and if designed carefully and co-ordinated in specification, are able to provide support to the AC network during faults.

AC PROTECTION

Protection systems underpin the ability of the wider system continue operation under fault conditions. The successful operation is dependant upon fault current provided by sources. Neither technology provides similar fault current to synchronous machines. LCC however provides limited discharge current and no sustained fault current, whereas VSC can provide limited fault current which with some additional development can help the AC protection to still operate successfully[12].

HARMONICS

The harmonic injections of the two technologies are very different. The relatively slow switching of the LCC convertors means that they inject significant harmonics at relatively low frequencies which generally leads to a requirement for extensive filtering, whose control and design can be material to how the onshore AC system recovers voltage, can contribute to converter interaction risk, and practically these filters account for a signifcant proportion of the footprint of the convertor station and introduce the potential to become outdated as the wider transmission system develops. VSC on the other hand requires no or limited filtering (normally a system filter rather than one driven by the convertor harmonics)[13].

SUPPORTABILITY

There is a shift in the manufacturing community towards standardising around VSC solutions for power electronic systems; this trend and the nature of bespoke design of technology challenges for any LCC convertor and its associated filters in a given application; places a significant challenge across an LCC-HVDC project lifetime. Ensuring relevant models are maintained, asset renewal/upgrades derisked and performance optimised as system strength changes will require particular focus for both parrallel and radial LCC-HVDC approaches over time that should be identified early within the projects delivery[14].

CONCLUSION

Multiple parallel LCC based HVDC links could be used when developing reinforcements however given the additional engineering challenges and equipment required to make it viable, a VSC solution would be preferable and in some cases essential. Additionally, VSC would have the benefit of being more future ready and immediately being able to support the grid in ways additional to have a boundary capability uplift.

References

1) National Grid ESO, *Future Energy Scenarios in five minutes*, July 2020, Available: https://online.flippingbook.com/view/621114/

2) OWIC, *Grid-access Technologes for GB Offshore Wind Industry*, January 2020, Available: https://www.hvdccentre.com/wp-content/uploads/2020/01/Grid-Access-Technologies_V3.pdf

3) CIGRE TB 821, *Capabilities and requirements definition for power electronics based technology for secure and efficient system operation and control*, 2020, Available: https://e-cigre.org/publication/821-capabilities-and-requirements-definition-for-power-electronics-based-technology-for-secure-and-efficient-system-operation-and-control

4) National Grid ESO, *Network Options Assessments 2021*, January 2021, Available https://www.nationalgrideso.com/document/185881/download

5) EPRI, *Adaptive Damping of Power Oscillations using HVDC, Available:* https://www.hvdccentre.com/pod_project/

6) ENTSO-E, *HVDC Links in System Operation*, December 2019, Available: https://www.entsoe.eu/Documents/SOC%20documents/20191203_HVDC%20links%20in%20system%20operations.pdf

7) National Grid ESO, *Offshore Coordination Phase 1 Final Report*, December 2020, Available: https://www.nationalgrideso.com/future-energy/projects/offshore-coordination-project

8) National Grid ESO, National Electricity Transmission System Security and Quality of Supply Standard, April 2021, Available: https://www.nationalgrideso.com/document/189561/download

9) National Grid ESO, *National Trends and Insights*, March 2021, Available: https://www.nationalgrideso.com/document/190151/download

10) National Grid ESO, *System Operability Framework 2015*, March 2021, Available: https://www.nationalgrideso.com/document/63461/download

11) Cardiff University, *Optimal control setting and PLL types with improved technical specifications considering grid strength for the stable operation of HVDC's in the GB system*, Available: https://www.hvdccentre.com/wp-content/uploads/2020/07/D2_CardiffR2_clean.pdf

12) EPRI, *Coordination of ac protection settings during energisation of ac grid from a VSC HVDC interconnector*, Available: https://www.hvdccentre.com/wp-content/uploads/2020/06/EPRI-Black-Start-from-HVDC-Project-final-report_reviewed_clean.pdf

13) DNV GL, *Holistic Approach to Offshore Transmission Planning in Great Britain*, November 2020, Available: https://www.nationalgrideso.com/document/182931/download

14) TenneT, *TenneT scaling up transmission capacity standard to accelerate offshore wind deployment*, January 2020, Available: https://www.tennet.eu/news/detail/tennet-scaling-up-transmission-capacity-standard-to-accelerate-offshore-wind-deployment/

15) PROMOTioN, *D12.4 - Final Deployment Plan*, September 2020, Available: https://www.promotion-offshore.net/fileadmin/PDFs/D12.4_-_Final_Deployment_Plan_Distributed_Version.pdf

Authors: Ian Cowan & Ben Marshall

E: info@hvdccentre.com

W: hvdccentre.com