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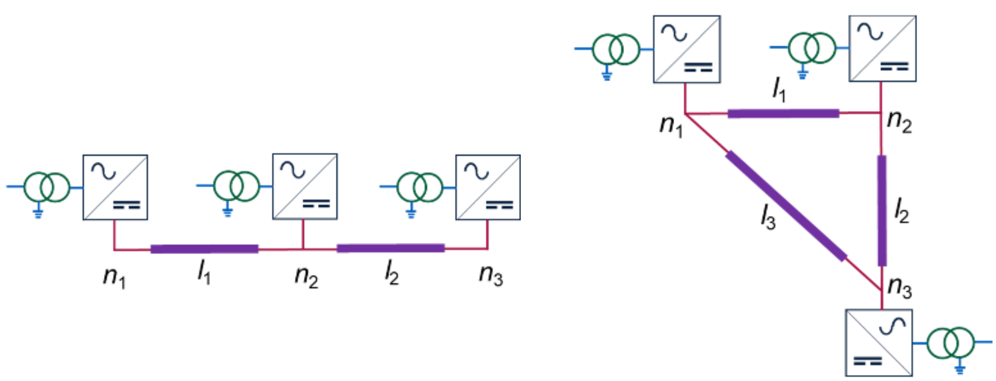
A number of methods to control the power flow within a HVDC grid have been well described in the literature [1, 2, 3, 4, 5]. In a simple radial system, comprising multiple power injection stations but only two stations that could actively control the HVDC voltage, a simple control philosophy based on DC slack bus control could be used. This type of control relies on only one of the two HVDC voltage controlling stations dynamically exchanging energy between the HVDC system and their associated AC networks. In the event that the HVDC voltage exceeds pre-defined limits the other converter capable of controlling the HVDC voltage can automatically take over with relatively simple 'handshaking' between the controllers. However, where the HVDC grid is more complex, comprising of more than two HVDC stations able to contribute to the HVDC voltage control and hence, the energy balance of the HVDC system a droop-based control is considered to offer more flexibility in the co-ordination of operation between the stations.

Whether DC slack bus or DC voltage droop control is employed the controller can only influence the power flow through the HVDC system by adjusting the DC voltage at a given node within that system. In a radial system, as an example, where the number of converter nodes exceeds the number of interconnecting transmission lines (i.e., in a radial system there will always be *n* transmission lines and *n+1* converter nodes) then controlling the converter DC voltage can fully control the power flow through each transmission line, Figure 1a. However, if additional DC transmission paths are added, forming a meshed grid, then simply controlling the node voltage does not permit control of the current through all the transmission lines individually, Figure 1b. This means that to maintain the current in a particular line below a defined limit it may be necessary to apply a constraint at a node that also reduces the power flow through adjacent circuits.

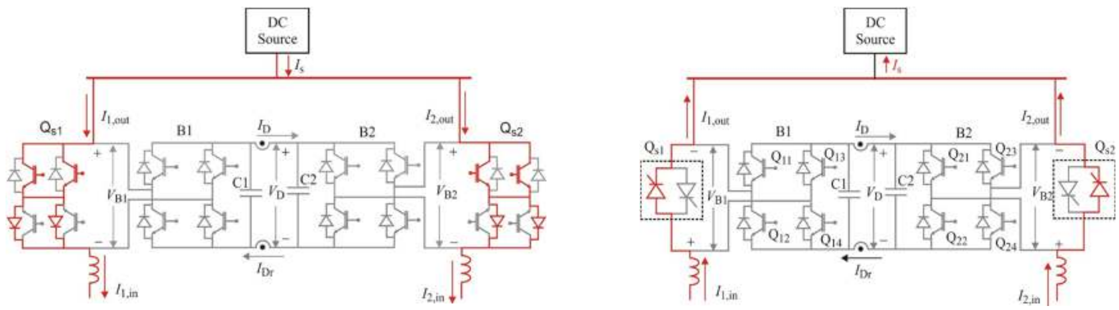


a b

Figure 1 : Radial DC system versus a DC grid
(a) Number of n_x > Number of l_x
(b) Number of n_x = Number of l_x

To overcome the constraint outlined above another class of device has been identified that can control the current sharing between DC lines. Broadly, these new devices fall into one of two types; Power Flow Controller (PFC) that transfers energy from an AC system and injects it in series with the transmission line, thereby requiring the power transfer of a relatively small amount of power between the AC source and the HVDC system via a transformer to provide galvanic isolation. The other type of device is the Current Flow Controller (CFC) [6, 7], this sits at the HVDC transmission voltage and adjusts the virtual impedance between two or more conduction paths thereby influencing the current sharing between these paths. This, therefore, obviates the need for a high voltage transformer.

The CFC (as the PFC) requires a means of fast bypass in the event of a dynamic overcurrent as the power electronic devices from which the CFC is constructed will have a limited current capability. Additionally, the CFC will not need to be in-circuit all of the time, it is only required when one of the line currents that are being controlled exceeds a threshold. Hence, to reduce losses, when not required it can be bypassed. The bypassing device could be an additional set of transistors, possibly connected in parallel to increase the current carrying capability, as shown in Figure 2a, or a pair of reverse parallel thyristors, Figure 2b. The thyristors have the advantage of offering lower conduction losses when the CFC is in the bypassed state. However, using thyristors as the bypass will require the addition of a device to pre-charge the CFC capacitor.



A b

Figure 2: Dynamic bypassing of a CFC
(a) Using Transistors
(b) Using Thyristors

Finally, a means of bypassing the complete CFC for maintenance is required. This device should be able to open in the presence of a DC current and commutate the current into the CFC. A device such as the Neutral Bus Switch (NBS) or HVDC circuit breaker can be used for this function but only need to be rated for a few kV between its terminals (but hundreds of kV with respect to ground) to be consistent with the voltage across the CFC, Figure 3.

References:

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