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Which design and technology aspects must be considered for multi-terminal HVDC transmission systems?

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In Europe, the main use case for multi-terminal HVDC (MT-HVDC) transmission systems is offshore networks connecting offshore wind farms to the main, interconnected, onshore AC transmission network [1], but it is not the only one; MT-HVDC can also be envisaged onshore, embedded within the AC system or even independent of it.

It has often been assumed that an MT-HVDC network would be protected in the same way as an AC transmission network, with circuit breakers usually deployed at each end of every network branch. This is justified for the AC network by the necessity to clear faults quickly with the minimum number of branches needing to be switched out of service in order to maintain system stability and ensure continuity of supply to demand. However, this approach presents a major challenge for MT-HVDC: circuit breakers on the DC side have not yet reached commercial maturity and widespread deployment, are technologically complex, and are likely to be expensive. On the other hand, fault clearance from the AC side of each terminal of an MT-HVDC network will be slow and entails both a very widespread voltage dip seen from the AC system during the fault and subsequent – if perhaps temporary – loss from service of the entire MT-HVDC network. This risks, for example, frequency instability on the AC system or the need to schedule a very large – and expensive – volume of frequency containment reserve.

An alternative approach to the use of expensive DC breakers on each end of each DC network branch is based on the recognition that continuity of supply from each offshore power source is not essential provided its loss is within the stability of limits of the AC system (or systems) to which it is connected. This can be ensured and protection simplified by adoption of the approach from distribution networks in which continuity of supply to every load is not required when a single fault event occurs: pre-fault partitioning of network through use of ‘normally open points’. Partitioning of an MT-HVDC network can be chosen so that only a subset of the DC network infrastructure experiences a voltage dip and loss of power transfer to the AC network in the event of a fault. Slow clearance for the AC side need not cause any more of a problem for the AC system than an AC network fault would. Identification of the fault location on the DC network will allow it to be isolated and the offshore network reconfigured permitting disconnected power sources to be returned to service where possible [1].

Although the analyses are now some years old and the cost and reliability data likely to be out of date, a study from 2015 reported in [2] shows that, taking asset costs and the costs of lost access to offshore energy into account and assuming that the usual onshore loss of infeed limits are respected, use of pre-fault partitioning of the offshore MT-HVDC network and fault clearance from the AC side of terminals can be more cost-effective than use of DC breakers.

References

[1] K.R.W. Bell, Lie Xu and T. Houghton, “Considerations in design of an offshore network”, *CIGRE Science and Engineering*, issue 1, February 2015

[2] Callum MacIver, Keith R. W. Bell, and Dusko P. Nedic, “A Reliability Evaluation of Offshore HVDC Grid Configuration Options”, *IEEE Trans on Power Delivery*, April 2016