Student Journal of Energy Research

Volume 1 | Number 1 Article 2

2016

Risk Assessment for Two Multi Terminal VSC-HVDC Control Schemes

Roberto Sandano
Dublin Institute of Technology, roberto.sandano@mydit.ie

Recommended Citation
Sandano, Roberto (2016) "Risk Assessment for Two Multi Terminal VSC-HVDC Control Schemes," *Student Journal of Energy Research*: Vol. 1: No. 1, Article 2.
doi:10.21427/D71B2Q
Available at: https://arrow.tudublin.ie/sjer/vol1/iss1/2

Risk assessment for two multi terminal VSC-HVDC control schemes

Roberto Sandano, PhD candidate
Student number: D13126370

School of Electrical and Electronic Engineering, DIT

10^{th} June, 2016

Contents

1 Introduction

High Voltage Direct Current (HVDC) connections have been in operation since the 1950s. The vast majority of which are point to point connections and use Line Commutated Converter (LCC) technology. Since the late nineties Voltage Source Converter (VSC) technology has become a feasible choice on HVDC transmission systems [1]. Research is now focused in the development of Multi-terminal (MT)-HVDC system which will facilitate the collection of energy from distant dispersed renewable energy resources and transport this energy to load centres.
Although some multi-terminal systems currently exist, they are rare, with two of them are still using LCC technology (SACOI and Quebec – New England Transmission) and just one of them (Nanao Project), recently commissioned, using VSC technology. The 2014 10-year network development plan by European Network of Transmission System Operators for Electricity (ENTSO-E) presents different Multi-terminal projects to be

implemented in Europe[1]. For e.g. the Project 189 Irish-Scottish Isles concerns the integration of offshore power which will contribute to the security of supply to the GB market and Single Electricity Market (SEM) on the island of Ireland [2].
In October 2015 the Network Code on HVDC Connections by ENTSO-E was voted on by Member States and is scheduled to come into force during 2016. ENTSO-E has drafted this Network Code on HVDC Connections and DC-connected Power Park Modules aiming at setting out clear and objective requirements for HVDC System Owners, DC connected Power Park Module Owners, Network Operators and National Regulatory Authorities in order to contribute to non-discrimination, effective competition and the efficient functioning of the internal electricity market and to ensure system security [3].
There is an understandable reason behind the upcoming regulation which requires the HVDC connections to be able to offer support systems to the stability of the main synchronous networks to which they are connected. For instance Articles 14 and 16 of [3] deal with active power regulation for synthetic inertia and frequency control. Under these articles the HVDC grid converter station is required to have the capability to provide to the relevant Transmission System Operator (TSO), an independent control mode to modulate the active power output to assist in maintaining stable system frequency.
In this context this paper introduces a risk assessment for an hypothetical multi-terminal HVDC transmission system between different European countries. The impact of such a transmission system would't be confined to a single national market and regulations and it would not be under the control of a single TSO.
A realistic layout of a multi terminal configuration is necessary in order to set the boundaries of the present job but it can be simply generalised extending the number of converters and/or nodes. The envisaged system consists of four converter terminals of which three grid connection points and a wind farm as shown in Figure 1.
The technical connection requirements for HVDC installations, as stated in [3], refer to the AC connection points of the relevant system. It is not clear yet if for multi-terminal or meshed systems these rules shall apply or not, it is indeed stated at the Art. 79 that the regulatory authority may attach any conditions to a decision concerning request for a derogation. In fact power park modules becoming connected to a meshed grid should have the possibility to apply, via an expedited process, for derogations to stated requirements. However it is predictable that such a regulation scheme will become compulsory for every kind of HVDC installations in the coming future. The synchronous inertia in Europe indeed is fast decreasing due to the ambiguous efforts of European governments to reduce carbon dioxide emissions on one end and on the other end to phase out from the carbon-free nuclear plants. The recent increased penetration of renewable energy sources has eroded the conventional plants profitability with the risk of early shutdown of these big synchronous machines which were responsible to maintain network stability [4] [5].
The control schemes of the multi-terminal HVDC installation considered here must, in addition to regulate the dispatch of wind power according to market requirements, be

[1]Following unless otherwise stated only VSC technology will be considered.

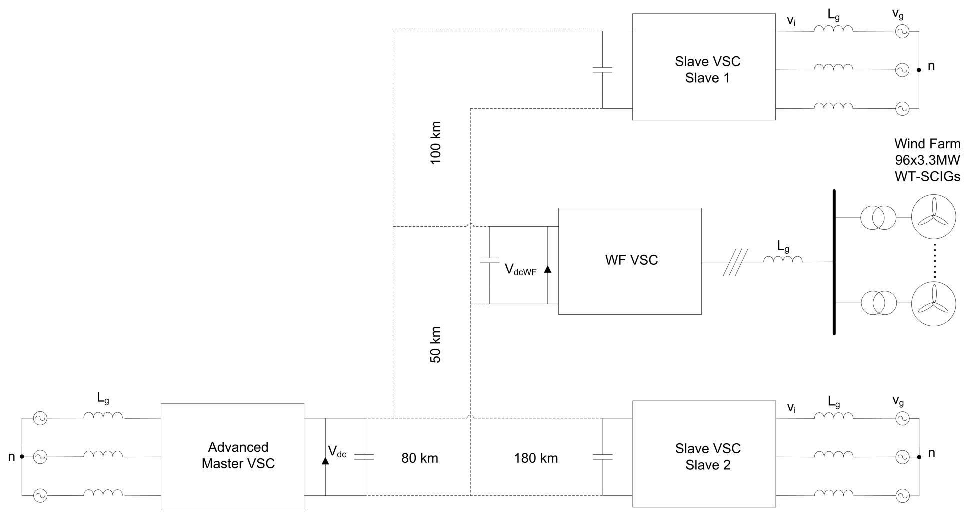

Figure 1: Four terminals used on the present simulation

designed to provide fast grid support services to every grid connection points.

2 Characterisation of control technologies

The technologies considered here follow the two major schools of thought in regard to the DC network management, i.e. master-slave with voltage margin against the droop DC voltage control.

Master-slave configuration means only one converter station, the master, to be in DC voltage control mode whereas all the remaining slave converters to be in active power control mode. Power factor correction is ensured in all the converter stations having each control logic two degrees of freedom to manipulate. Master-slave technology naturally entitles all slave converter terminals to provide a complete range of grid support services whereas the master converter relies in turn on its connected AC grid.

On the other hand droop control technology in its classical definition in [6] does not consider any regulated power flow but its aims are to control the DC voltage to ensure the energy collected by the wind farms is transmitted to the grid networks, and to distribute the generated power between the grid networks according to pre-defined criteria. For this reason here it is considered an improvement of such scheme presented in [7] which share the power mismatch in one converter on all the others in order to minimize the deviation in the AC system frequency.

A risk identification on respectively master-slave and droop control schemes is now necessary in order to assess which technology should be adopted in a real multi terminal HVDC application to be based in Europe under the ENTSO-E network area.

2.1 Master-Slave with voltage margin

Master-slave control theory is the natural extension of the adopted control schemes on the existing point-to-point VSC-HVDC installations. For these links indeed, the usual practice is to operate one of the converter stations in active power control mode to ensure the scheduled power exchange. The DC link voltage is maintained by the other station which consequently supplies also the resistive losses in the DC link acting as a slack converter station.

Master-slave relies on a single converter station to control the DC voltage and in case of failure the voltage-margin technology [8] ensures that another converter station would become the new master. The advantage of master-slave control scheme is that every slave terminal is allowed to provide a complete range of ancillary services, from the primary frequency regulation on the AC side until the AC voltage stability through injection or withdrawn of reactive power. On the contrary the master converter is responsible for the DC voltage of the whole DC network. Hence it relies on its own AC side for the necessity to increase or to reduce the power to fulfil the sudden requests of regulation on an annexed slave converter.

The strategic importance of the master converter must be addressed at the planning stage because of the relevance on the stability of the whole DC network and on the primary provision of all the ancillary services used on the slave converter terminals. Collateral works are always necessary on the installation of a HVDC plant such as filters and power factor correctors but the coming of such a multi terminal system would re-design the transmission and generation system of the local area. To clarify VSC technology based on IGBT is much more flexible than LCC (thyristor based) but still the impact of such a transmission system it is not free of charges.

A possible solution to adopt together with the installation of the master converter could be a reserve with very fast dynamic dispatch capability, it might be a gas turbine or a hydro pumping storage, flywheel generator could also help to provide the necessary inertia.

Apart from the initial capital costs of the installation of the so-called slack DC bus with the annexed complementary works the master-slave configuration does not need to be constantly monitored with a fast global communication system. All the grid point connections are indeed under normal market activities means dispatching power according to market requirements. Standard market operation communications from the TSO have not to be confused with the actual reading of currents and voltages for the inner control logic of each converters. Truly these inner control values are already currently exchange on the HVDC point to point connections trough optical fibers inside cables but they are considered as an accessory over a control pillar. If some sort of delays arise as jitter effects or communication losses the multi terminal plant would continue indeed to dispatch power regularly.

2.2 Autonomous power sharing with frequency control

As stated above the original DC voltage droop control fitted with the initial characterisation of the not-programmable renewable energy resources. They indeed were considered as protected from a market largely dominated by conventional power plants hence a priority of dispatch was largely applied. A first evolution from the initial droop scheme was autonomous power sharing proposing that the droop coefficient shall be calculated based on a function of the normalized available headroom of each converter. This evolution envisages the use of the previous avoided global fast communication system. Here the intrinsic necessity of the communication system need to be guaranteed for the entire lifespan of the transmission system. Naturally the failure of this system is not parallel with for example the transmission cable failure hence the Mean Time Before Failure (MTBF) of the compound serial failures is higher by definition.
Autonomous power sharing scheme is still not capable to provide ancillary services hence in order to change the power sharing amongst different converter stations for the frequency support of the adjacent AC systems, the real power reference of the converter stations must be modified. Here it is considered the proposal from [7] where a supplementary frequency droop control is adopted on the active power references.
The main advantage of this proposal is that there is not a main converter station acting as a master hence theoretically the impact of such an installation would not see any difference between the all terminals. The used conditional wants to point out that the ratio behind this droop system is that rather than having a large and potentially unacceptable variation in the frequency of the affected system, there would be relatively small variations of frequency in all the AC systems. The extent of variation of frequency naturally would depend on the nature and size of the disturbance and also on the inertia of the systems [9].

3 Case study Denmark as a multi-terminal HVDC system

Taking advantage of the long term concept envisaged in the last Ten Year Network Development Plan (TYNDP) 2016 by ENTSO-E [10], it is proposed an appraisal of the mentioned control technologies evaluating the risks associated with their installation on the ENTSO-E concept.
In Figure 2 it is shown the proposal of a multi-terminal to connect several countries in North Europe around Denmark as shown again in [10]. The main drivers behind this potential multi-terminal HVDC system are its cost-efficiency, technical advance and reduced stress on the internal HVAC transmission system. The cost-efficiency is emphasized through that the multi-terminal HVDC system would need fewer HVDC converter stations for facilitating the same number of HVDC connectors and the same energy and power transport between the areas.
Adopting an advanced droop control strategy, as the one presented above, it would de-

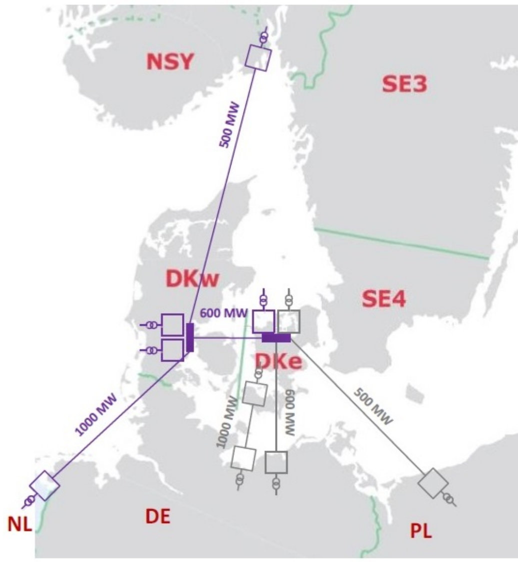

Figure 2: The map shows Denmark-West (purple) and Denmark-Est (grey) projects as a multi-terminal HVDC system, using five VSC-HVDC stations instead of using seven in a analogous point-to-point configuration. [10]

mocratized the system making it almost isotropic. Apart from the different capacity of the connectors in fact the various converter stations are stand-alone in relation to their AC connected grids. Analysing the risk of a severe demand of primary regulation on one terminal it results on a immediate sharing the burden to all the others. None of the AC grids would have been re-designed to provide such fast regulation interventions so the risk would be that to guarantee one network severe stability issue many others AC network would follow.

On the other hand the adoption of a master converter station in the proposed system in Figure 2 would mean to choose the strongest grid to be connected with it in order to have the highest short circuit ratio needed for the provision of the grid support services to all the other slave converters. Taking for granted that the adoption of such a system would mean to engineer the grid in order to support the master station the major risk associated would be the sudden lack of it. The voltage margin method as discussed above would nominate automatically a pre-defined new master. However it is very difficult to imagine that a new master would have been designed to sustain the provision of support services itself hence the lack of the master must be sustained with an immediate provision of emergency manoeuvres on each grid connected, such as the activation of some fast conventional generation plants or curtailing renewable energy sources in order to keep a reserve.

4 Conclusion and future recommendations

The present short essay wanted to provide a starting stage of a complete risk assessment for the choice of the control technology to adopt on the installation of a multi terminals VSC HVDC transmission system. The system analysed visible in Figure 2 is entirely a transmission system whereas mostly the multi terminal DC system are considered for the collection of dispersed renewable energy resources. This should be read as the impelling necessity of the various TSOs to solve the inevitable upcoming primary regulation shortage.

Having analysed the two control logic impacts on the installation of a multi-terminal it is now possible to point out some basic economical principles. Differently from many other fields where control logic can simply be changed along the way or even during the operations, here the choice has a considerable clout.

From the perspective of the initial capital costs the solution with the DC voltage droop control might be preferable whereas the solution with a master converter station would be the one with the lowest operational costs because of lower monitoring necessities.

The size of the considered system could demand for the application of the Arrow-Lind theorem in which the social cost of the risk tends to zero as the population tends to infinity, so that projects can be evaluated on the basis of expected net benefit alone. Unfortunately one of the conditions to fulfil is that the government initially pays all costs, distributing the net returns subsequently through changes in the level of taxes [11]. It is clear that the actual fiscal condition experienced by European countries, in which the budgets are affected by continuous restrictions, need that the risk analyses for the decision making to be as much as possible rigorous and science based.

References

[1] SCB4 committee of CIGRE, *"VSC Transmission,"*, TB 269 2005 SC B4 WG B4.37, Last Accessed: February 20^{th}, 2016. [Online]. Available: http://b4.cigre.org/Publications/Technical-Brochures/TB-269-2005-SC-B4-WG-B4.37-VSC-Transmission

[2] European Network of Transmission System Operators for Electricity, *"10-year Network Development Plan 2014,"* Last Accessed: January 29^{th}, 2016. [Online]. Available: https://www.entsoe.eu/major-projects/ten-year-network-development-plan/tyndp-2014/Documents/TYNDP%202014_FINAL.pdf

[3] European Network of Transmission System Operators for Electricity, *"Final draft Network Code on HVDC connections - October 2015,"* Last Accessed: February 18^{th}, 2016. [Online]. Available: https://www.entsoe.eu/Documents/Network%20codes%20documents/NC%20HVDC/HVDC_110915_Final_Provisional_Voted.pdf

[4] Jan Hromadko, *"Germany's E.ON to Shut Down Nuclear Reactor Early,"* The Wall Street Journal, 28^th March, 2014 [Online]. Available: http://www.wsj.com/articles/SB10001424052702304418404579467023883510280

[5] Reuters report, *"Sweden nears deal to phase out nuclear tax over four years - report,"* Reuters, May 31^{st}, 2016, [Online]. Available: http://www.reuters.com/article/sweden-nuclearpower-tax-idUSL8N18S186

[6] Lie Xu, Liangzhong Yao and M. Bazargan, *"DC grid management of a multi-terminal HVDC transmission system for large offshore wind farms,"* in Sustainable Power Generation and Supply, SUPERGEN '09, pp.1-7, 6-7 April 2009

[7] N. R. Chaudhuri, R. Majumder and B. Chaudhuri, *"System Frequency Support Through Multi-Terminal DC (MTDC) Grids,"* in IEEE Transactions on Power Systems, vol. 28, no. 1, pp. 347-356, Feb. 2013.

[8] T. Nakajima, and S. Irokawa, *"A control system for HVDC transmission by voltage sourced converters,"* in Power Engineering Society Summer Meeting, IEEE, 1999, vol.2, pp.1113-1119

[9] N. Chaudhuri, B. Chaudhuri, R. Majumder and A. Yazdani, *"Multi-terminal Direct-Current Grids: Modeling, Analysis, and Control,"* Wiley 2014, ISBN 9781118729106

[10] European Network of Transmission System Operators for Electricity, *"Regional Investment Plan 2015 North Sea region - 30 October 2015,"* Last Accessed: February 18th, 2016. [Online]. Available: https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202016/rgips/Regional%20Investment%20Plan%202015%20-%20RG%20NS%20-%20Final.pdf

[11] L. P. Foldes and R. Rees, *"A Note on the Arrow-Lind Theorem,"* in American Economic Review, 1977, Vol.67(2), pp.188-193.