Strathclyde Engagement with the National HVDC Centre: Development and Validation of LCC-HVDC and Type 3 Turbine Impedances

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Prepared by:	Lie Xu University of Strathclyde		09/09/2021
Approved by:	Lie Xu University of Strathclyde		09/09/2021
Authorized by:	Ben Marshall The National HVDC Centre		04/11/2021
Accepted by:	Simon Marshall The National HVDC Centre		08/11/2021

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1. Project background

Increased network interconnection and connection of large offshore wind farms using HVDC links, the GB power network will see significant numbers of HVDC converters connected in close proximity. To assess system stability and dynamic interaction between grid and converters, the impedance-based stability analysis is an effective method of identifying potential frequencies of disturbance to which an individual converter may be vulnerable to destabilizing behaviour. Therefore, the accurate capture of each converter's frequency dependent impedance model is critical to identifying network states where the risk of instability may exist.

Previous collaborations between the University of Strathclyde and the National HVDC Centre have developed frequency domain network / MMC converter models adequate for small signal stability analysis. Recommendations for specification and operation requirement of MMC based HVDC systems have been proposed when obtaining frequency domain HVDC converter models. Using the developed network and MMC small-signal impedance models, the stability of multiple converter systems has been studied. The approach uses small signal methods to identify with good alignment to EMT dynamic simulation those operating states of MMC based HVDC systems and the transmission networks between them where interactions between converters most likely may arise. In a transmission network however MMC converters are not the only dominant source of frequency dependency and both the effect of LCC HVDC converters or the cumulative effect of similar wind turbine generators frequency dependency also has a bearing on what operational conditions may give rise to interaction, between what devices and should then be considered further within EMT analysis.

This project extends the previous modelling work and concentrates on the development of small-signal LCC HVDC system model. Considering the impedance behaviour of Type 3 DFIG based wind turbine system is less known compared to that of Type 4 turbine, this project also develops and validate the small-signal impedance of Type 3 wind turbine. The developed impedance models can then be used for assessing stability and interactions between different converter systems (e.g., MMC, LCC, wind farm, etc.).

2. Project Objectives

The project develops and validates frequency-dependent converter impedance models for stability analysis of complex networks, including LCC HVDC system and Type 3 wind turbine.

A. Develop and validate frequency-dependent impedance model of LCC HVDC system

Due to the existence of significant 11th and 13th harmonic current inside the LCC converter, there potentially can have significant harmonic interactions at relatively high frequency, i.e. around 600 Hz for 50 Hz AC system. Thus the main activities are: developing typical LCC HVDC system model in RSCAD based on the existing generic Cigre benchmark model, and developing small-signal impedance model of LCC HVDC system, and cross-validation with the impedance measurement from the RSCAD model.

B. Develop and validate frequency-dependant impedance model of Type 3 turbine

With typical power control strategies, small-signal model of Type 3 turbine is developed and cross-validated with measurements from time domain model. Main impedance differences between Type 3 and Type 4 turbines are also assessed.

3. Project Findings

For LCC HVDC system:

The behaviour of LCC converter is non-linear in nature given thyristor switching, and hence the small signal model needs to be derived from the given operating mode of the thyristors linearised from time domain operation of the given model. An analytical model similar to that of the MMC describing a 2x2 admittance matrix at the AC terminals can be used to represent the small signal behaviour of the LCC system. The obtained LCC impedance/admittance results show that:

- The admittance matrix of an LCC system can be represented by a 2x2 matrix, similar to other converter systems. Thus, a network that contains different converter technologies can be assessed by considering the impedance of each converter and the AC network.
- LCC converter operating point such as power and firing angle affects the impedance, though less significantly than has been observed in VSCs, e.g., MMC.
- The control mode (e.g., DC current control, DC voltage control) impacts the converter admittance. However, the controller parameters (e.g., PLL and controller gains etc.) only have a small impact on the converter admittance.
- AC filters at LCC converter terminal significantly affect the overall impedance especially at a higher frequency range, e.g., above 100 Hz. As such tuned filters are in service for a given operating point and operating mode of the converter must be specified and included in the reduction undertaken.
- For an LCC transmission system, the AC impedance at one terminal is affected by the DC side impedance of the other terminal, while DC side impedance is affected by the converter control mode and the AC network condition (network strength) for which the converter is connected to.
- Thus, LCC AC impedance at one terminal can be affected by the AC network condition of the other terminal, though such impact is mainly on the low-frequency area, e.g., below 100 Hz. This mainly impact on the AC impedance of the rectifier side during low network strength at the inverter terminal.
- As such a range of short circuit strengths to define the AC network condition of the external network at different times of study for interactions below 100Hz is advisable, especially cases with the lowest possible SCR at the inverter terminal should be considered when studying the stability of the rectifier AC system.

For Type 3 turbine

The small-signal impedance models of both Type 3 and Type 4 wind turbine systems have been presented, considering different control modes including current control (CC), active power and AC voltage droop control (PV) and speed and AC voltage PI control (WV). Analysis confirms that:

- CC mode offers the lowest admittance and highest damping indicating the most stable approach for both types of turbines. However, the Type 4 turbine admittance is highly sensitive to operating point changes while in CC mode.
- For the Type 4 turbine PV control which is commonly adopted in wind farms in GB gives the highest admittance and lowest damping, while both PV and WV are similar for the Type 3 considering the entire frequency range.
- Overall, the Type 4 turbine offers a much lower admittance and higher damping at all operating points for all control modes. This suggests that Type 4 turbines may suit a stronger grid connection while Type 3 could operate better for weaker connections.