Passive filter design and wind turbine modelling for system level harmonic studies

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Introduction

This poster presents passive filter design and voltage source converter control, which are two key aspects for grid integration of offshore wind turbine generators with full-scale converters. The objective is to create a framework for system level analysis of harmonics in offshore wind power plants.

Modern wind turbines employ power electronic converters with capacity of several megawatts. Such converters increase the flexibility and efficiency of generation, but also bring new challenges. The converters typically require harmonic filtering at the grid side connection point in order to comply with grid code requirements on harmonic emissions.
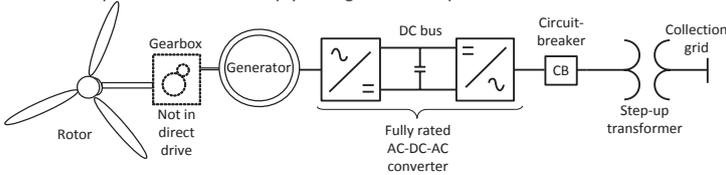

Figure 1: Layout of wind turbine with full-scale power electronic converter

LCL filter tuning and analysis

An LCL filter has better performance than a pure inductive filter of similar size. It also has inductive output, thus it is capable of limiting current inrush problems, and it has little dependence on grid parameters. These characteristics allow it to find broad application in the grid integration of power electronic converters.
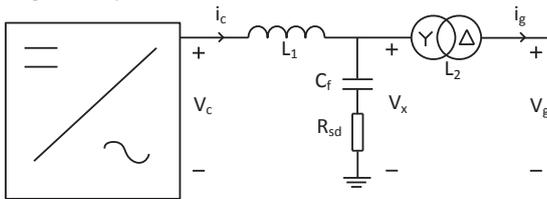

Figure 2: LCL filter with components nomenclature

Unlike a pure inductive filter, an LCL filter has a resonance frequency which must be taken into account when selecting parameters for the filter. The resonance frequency is given by

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{L_1 + L_2}{L_1 L_2 C_f}}$$

and should be carefully placed considering the harmonic spectrum in order to avoid resonance problems. Furthermore, either passive or active damping of the filter resonance should be applied. The most basic form of passive damping simply requires inserting a resistor R_{sd} in the shunt branch, as shown in figure 2, but this form of damping leads to high losses and reduced attenuation of harmonics.

LCL filter topologies with various passive damping schemes can be analysed using bode plots of filter transfer functions. The transfer function relating the applied voltage from the converter to the resulting filter output current indicates how well harmonics are attenuated by the filter, and how well the resonance of the filter is suppressed.
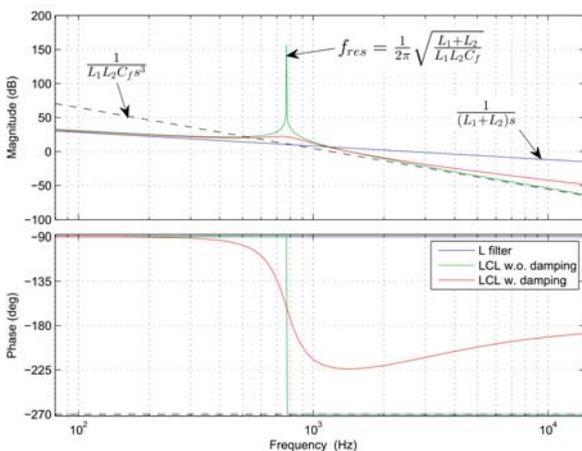

Figure 3: Bode plot of transfer function $Y_{cg}(s) = \frac{i_g(s)}{v_c(s)}$ for L-filter, undamped LCL filter and damped LCL-filter

The capacitor of an LCL filter is in itself a high-pass filter, providing a low impedance path to ground for high-frequency harmonics. The simple RC shunt branch can be replaced by a more complex passive high-pass topology, resulting in better attenuation of harmonics and lower losses, while also damping the filter resonance. Some of the possible high-pass filters are shown in figure 4.
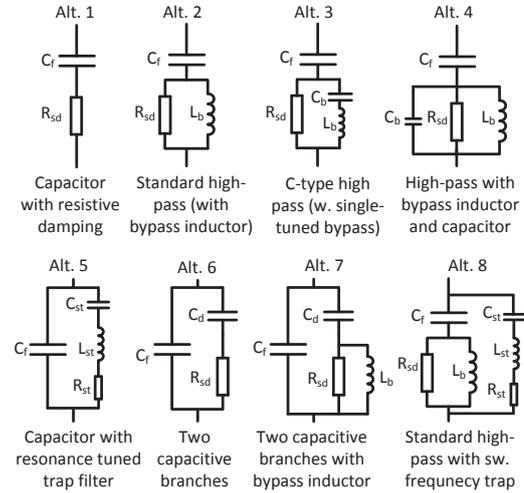

Figure 4: Possible high-pass topologies for LCL filter shunt branch

Converter control

A simulation model of a two-level voltage source converter with closed loop control in the dq synchronous reference frame has been built for representing wind turbine generators in harmonic studies. The dynamics of the system is represented by,

$$\begin{bmatrix} v_{d,x} \\ v_{q,x} \end{bmatrix} = -L_1\begin{bmatrix} i_{d,g} \\ i_{q,g} \end{bmatrix} - R_1\begin{bmatrix} i_{d,g} \\ i_{q,g} \end{bmatrix} - \begin{bmatrix} 0 & -\omega L_1 \\ \omega L_1 & 0 \end{bmatrix}\begin{bmatrix} i_{d,g} \\ i_{q,g} \end{bmatrix} + \begin{bmatrix} v_{d,c} \\ v_{q,c} \end{bmatrix}$$

Closed loop current control has been implemented as illustrated by figure 5. The parameters of the PI regulators have been tuned using the Modulus Optimum Criterion.
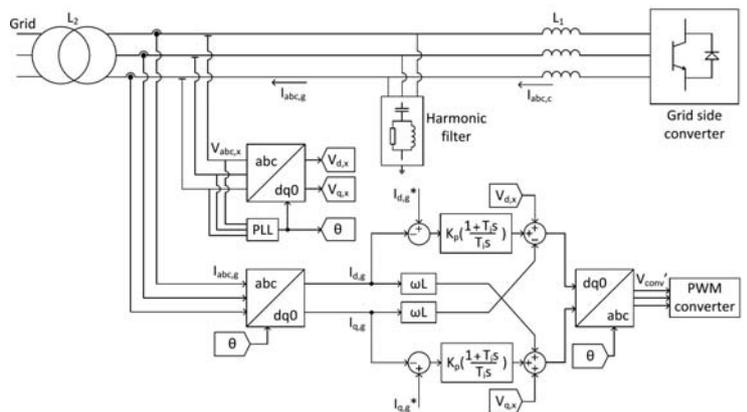

Figure 5: Implementation of current control loops in the dq axis reference frame

Conclusions

LCL filters require careful selection of their parameters in order to avoid resonance problems. Additional passive elements installed in the shunt branch of the LCL filter allows for effective damping of the filter's resonance, while also providing low losses and maintaining harmonic filtering performance.

A framework has been created for further analysis of harmonics in offshore wind power plants. Future work will build on the analysis and modelling performed so far to create an integrated simulation model for system level harmonic studies in the time domain. There is also potential for further investigation of the converter control strategy, including topics such as closed loop stability limits, active damping and active filtering.