PhD Public Defence

Title:	Optimal Design of Passive Power Filters in Grid-Connected Voltage-Source Converters
Location:	Pontoppidanstræde 111, auditorium
Time:	Friday 24 June 2016 at 13.00
PhD defendant:	Remus Narcis Beres
Supervisor:	Professor Frede Blaabjerg
Moderator:	Professor Francesco Iannuzzo
Opponents:	Associate Professor Deszo Sera, Dept. of Energy Technology, Aalborg University (Chairman)
	Dr. Vladimir Blasko, United Technologies Research Center, East Harford, USA
	Professor Detlef Schulz, Helmuth-Schmidt-Universität, Hamburg, Tyskland

All are welcome. The defence will be in English.

**After the public defence there will be an informal reception
in Pontoppidanstræde 111 (coffee room).**

Abstract:

The use of multiple grid-connected Voltage-Source Converters (VSCs) creates harmonic interactions between the multiple harmonic sources and the passive components tuned for different frequencies. The results are harmonic resonances in a wide frequency spectrum which may lead to amplification of individual harmonics in certain operating conditions, leading to harmonic instability. This phenomenon is currently increasing with the spread of power electronics based harmonic sources, e.g. HVDC stations or VSCs based power generation. In addition to the harmonic impedance of the grid, it has been shown that in a grid-connected VSC, the harmonic instability is influenced by the design of passive filter, tuning of current controller parameters or the time delay associated with the digital computation. However, most of research that address harmonic interactions assume uncertain filter parameters and focuses mainly on the design of the current controllers with active damping to damp harmonic oscillations, few about passive damping due to the additional power loss in the resistors and even few about the time delay.

The harmonic stability condition can be evaluated by the ratio between the harmonic grid impedance and the output impedance of the VSC. However, there is limited information about the output impedance of VSCs. One problem are the passive filters which in most situations are designed with trial and error design approaches which lead to an unknown output behavior of the VSC, especially for cost-optimized filters which adopt smaller inductors and larger capacitors. Other known issues include the passive components, especially the filter inductors which exhibits non-linear dependence of their equivalent inductance and resistance with the operating current, frequency or temperature. And it has been recently shown, that the inductor on the converter side of the filter lead to much higher losses than expected due to rectangular voltage excitation from Pulse Width Modulation (PWM). Then, the equivalent power loss of the inductor contributes to the inherent damping from the filter and is dependent on the operating flux density ripple given by the excitation voltage, dc bias magnetic field of inductors, or the adopted magnetic core material. Therefore, several aspects concerning the passive filter which significantly influences on the VSC output impedance are investigated as follows:

- In-depth characterization of passive components under PWM excitation to describe their inherent damping
- Passive filter topology and its output characteristics
- Parameter selection of passive filters to meet performance criteria

The LCL filter is the simplest and most adopted high-order passive filter for use in VSCs. Based on the knowledge and experience gained on the LCL filter, new and more efficient passive filter topologies are adopted which can further reduce size and cost. The use of single or multi-tuned traps in the filter instead of the single capacitor is one example of such filter. However, increased component count in the filter makes the design of the filter more complicated. Under the presence of an additional passive damping circuit which is adopted to damp the filter resonances, the design becomes even more iterative and difficult. Hence, a new method is presented which simplify the passive filter design and which ensure maximum damping performance. In short, the optimization and design problem reduces to the proper choice of the multi-split capacitors or inductors in the high-order filter. Additionally, the proposed method provides lower damping capacitors or inductors and a lower rated damping resistor. Since the use of single or multi-tuned traps in the filter increase the harmonic current in the filter as result of decreased size of passive components, conventional passive damping solutions leads to relatively high loss. Therefore, a new passive damped filter topology is presented which offers a good trade-off in terms of size and loss compared with the traditional LCL filter and the single-tuned trap filter. To differentiate between the features of different passive filter topologies, an in depth comparison and analysis is completed. The passive filters are designed to meet the same performance criteria, e.g. same rules for

component sizing and stability margins. The passive filters are evaluated in terms of damping capability, stored energy in the passive components and power loss in the damping circuit. The evaluation of passive filters is performed for different operating conditions including different switching frequencies, attenuation requirements and position of the current sensors. It is shown that relatively low damping loss can be obtained while adopting passive damping solutions.