Reducing Passive Filter Sizes with Tuned Traps for Distribution Level Power Electronics

(Topics: 16e,16c - Lecture Preferred)

Abstract

This paper proposes a filter topology intended for use with medium voltage grid-interfaced power electronics as an alternative to the widely-utilized LCL filter topology. Results indicate a reduction in peak stored reactive energy and total losses while meeting performance requirements for grid interconnection.

Background and Motivation

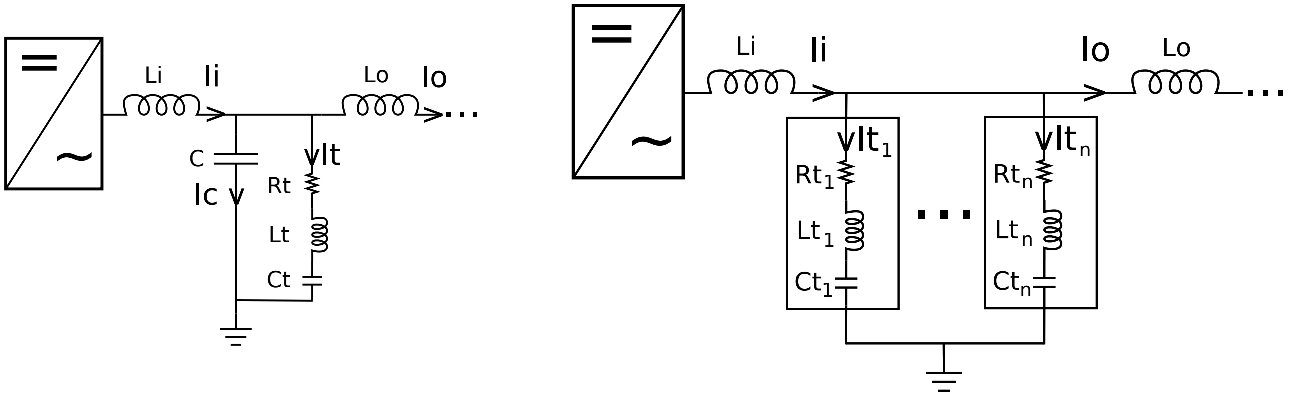
Power electronics implemented at the distribution level bring about a new set of challenges for the designer; specifically, the application of high power three-phase voltage-sourced converters (VSCs) and their associated passive components will have limits on the physical space which they consume, especially so for urban environments where available space is often at a premium.

The three primary components which comprise the bulk of the total convert volume are the valves, the passive components (filters) and the cooling system [8]. This paper addresses the issue of filter component size and proposes an alternative topology.

For grid connection applications, the filter must be designed in order to meet regional grid-interconnection requirements [1] with limitations, such as the converter DC bus voltage, considered. Despite their simplicity, purely inductive filters are not utilized for these applications due to high inductance value required in order to meet these requirements. The overall size will be large and the reactive power output capabilities for a given maximum converter output voltage (restricted by the DC bus voltage) are limited by this large inductance [5]. A widely used topology for high power, medium voltage, motor drives is the LCL filter [8], which offers similar performance with a much lower size when compared with a purely inductive filter [5]. The trade-offs for this reduction in size is an increased component-count as well the requirement for damping the resonance inherent to this topology. Both active and passive options for damping can be utilised [3]. In order to actively damp via control of the inverter, it is necessary to keep the resonance peak within the controller bandwidth [6] which puts further restrictions on component selection. In addition, some passive damping is required for times in which the VSC is disabled, as there is potential for excitation of this resonance from grid-side events.

The LCL design that will be benchmarked against is shown in Figure 1a. This topology includes a resonant filter tuned to that of the LCL components intended to reduce the peak gain at the resonant frequency.

The proposed alternative topology, shown in Figure 1b, makes use of *n* RLC shunt trap filters between the ripple inductor, *Li*, and grid-coupling inductor, *Lo* in order to increase the attenuation of high frequency components sourced by the VSC. The use of multiple traps allows the shunt capacitor to be removed entirely while still meeting performance requirements, and offers a reduction in peak stored energy for all filter components relative to the benchmark topology.



(a) LCL filter with trap tuned to resonant frequency (benchmark)

(b) Proposed filter topology with *n* shunt RLC traps

Figure 1: Filter topologies under study

Component Selection and Design Parameters

In the benchmark LCL filter of Figure 1a, Li, Lo and C are selected in order to meet the grid connection requirements [1] while minimizing size and losses. The single RLC trap is tuned to the resonant frequency of the LCL set.

The multiple-trap has additional parameters including the resonant frequency of the trap (frn), the damping resistance (Rtn), and capacitance (Ctn) .

The ripple inductor is often selected to meet a specific current ripple requirement, accounting for the the rated converter output current, It, plus a crest factor defined by the frequency and DC bus voltage [7]. These parameters selected to meet grid-interconnection requirements while achieving a similar frequency response and losses to that of the LCL topology. Constraints involved in parameter selection include:

- the maximum reactive power that can be sourced for grid support (for a fixed DC bus voltage) - limits have been placed such that for a given DC bus voltage, the converter can source reactive power with a power factor of 0.75
- the total losses in the passive components of the filter
- the total harmonic distortion (THD) for high order harmonics

The estimated size, calculated according to peak energy, is used to evaluate a given set of parameters (component values). In addition, the fundamental X/R ratio is set to 50 for all inductive components, and ESR of capacitor components is considered negligible.

Size Estimation

The system is characterized in the frequency domain for the spectrum of interest, that is at multiples of the fundamental up to ten times the switching frequency, plus sideband components, in order to account for any significant peak currents and voltages in all reactive components.

In order to evaluate peak inductor currents and peak capacitor voltages, and thereby determine peak energy requirements for passive components, all feasible operating points are considered, i.e. all possible inverter terminal voltage phase angles. That is, those operating points which do not exceed the specified rated inverter output current or maximum inverter fundamental output voltage for a given modulation index, ma. The largest current/voltage for each reactive component of the filter is selected amongst all of the feasible operating points and this figure is used for attaining a size estimate.

Size estimation is less certain of a process due to variations in manufacturer processes and other design parameters, as well as taking into account how the cooling system scales with losses and volume. Some techniques were considered for the estimation of inductor and capacitor volume [4]; however it was deemed appropriate to use manufacturer data for passive components of the appropriate rating and inductance/capacitance in order to come up with a mean constant of volume versus energy. While final realizations will not follow this constant scaling, it is critical to the component selection that the relative scaling of inductor volume with peak energy versus capacitor volume with peak energy is realistic for component selection.

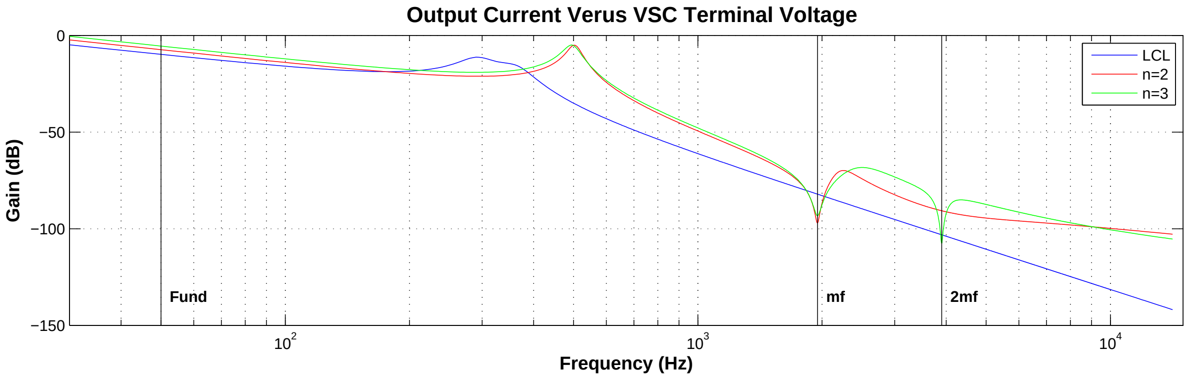


Figure 2: Frequency Response for the two filters compared

Results

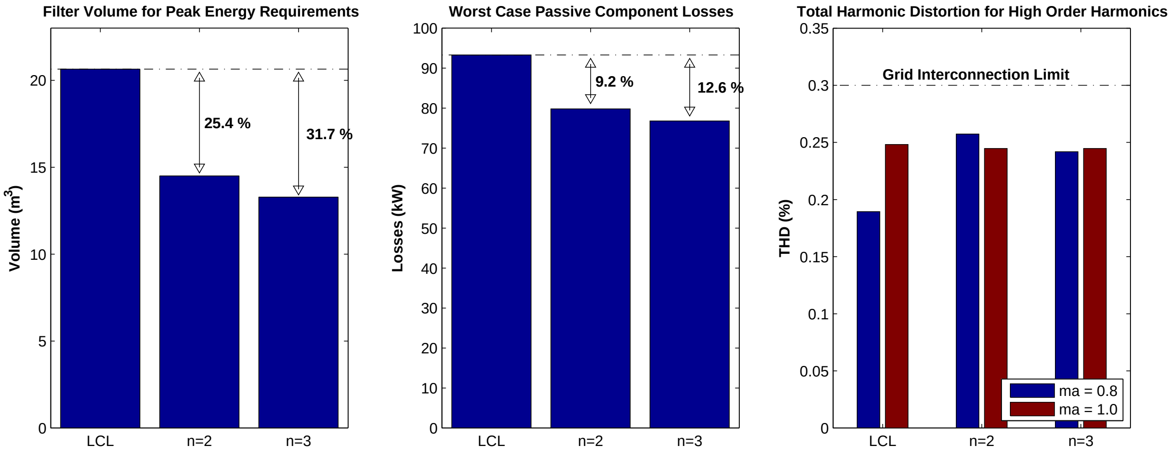
Optimization is performed via a custom genetic algorithm with fitness of a given solution evaluated according to the size estimation method described previously. Preliminary results indicate that the size reduction, while meeting constraints, was greatest with traps tuned to multiples of the switching frequency. Results for a two-trap and three-trap filter are presented in this report. Figure 3 shows size estimates for the benchmark topology versus the proposed multiple-trap topology attained using this size estimation technique. Note that for the results shown, a 2-level VSC is considered. If a multi-level converter topology is considered, it is possible to reduce the size of the filter further due to the reduced high frequency harmonic content.

Figure 2 shows the frequency response for the two filter topologies being compared for the transfer function $\frac{Io}{Vt}$, that is, the output current to the VSC terminal voltage. The multiple-trap topology provides the same attenuation at the switching and switching sideband harmonics. Although the attenuation is greater going higher into the spectrum, it is still sufficiently high when the frequency spectrum of the input voltage is considered.

In terms of percentage size reduction, the multiple trap filters provide an estimated size reduction of 25-30%.

The worst case overall filter losses amongst all feasbile operating points are shown in Figure 3. The total losses depend primarily on the number of traps as well as the damping present in each trap. In addition, the losses associated with the filter when the inverter is off, or exporting no power, are reduced for the multiple-trap case.

The proposed filter topology has been shown to be stable in time-domain simulations with a closed-loop current control system including the active damping strategy proposed in [2] in order to mitigate the low order resonance phenomenon. Results have been excluded for brevity.



Filter Volume for Peak Energy Requirements

Worst Case Passive Component Losses

Total Harmonic Distortion for High Order Harmonics

Figure 3: Size based on peak energy, passive component losses, and THD for two filters compared

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