New Passive Filter For PWM Based Devices

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Abstract

This paper presents a new passive filter, which is based on a foil inductor and called hybrid *LC* filter (HLCF). The HLCF integrates inductance and capacitance in one component. This is achieved by using an auxiliary foil placed between the turns of the main foil. The stray capacitance, harmful in traditional foil coils, is thus cancelled in the HLCF and converted into a useful capacitance between the main and auxiliary foils.

1. Introduction

Pulse-width modulation (PWM) based devices have found wide industrial implementation. However, PWM sequence of pulses contains high-frequency harmonics, which are not required by the control, but contribute in noise. The noise can cause damages of the load, problems with electromagnetic compatibility, increased losses and excess heat of the load. The filters used in devices with PWM should effectively operate in a wide range of frequencies. However, the stray impedances existing in a filter worsen the high-frequency attenuation. Thus, the commonly used filters are not capable to protect the loads from the adverse effects of the PWM.

2. Hybrid LC filter

In high-frequency applications, e.g. in power drives, foil inductors are widespread because of their low DC and AC resistances. In order to avoid short-circuits, essential surfaces between coil turns have to be separated by insulation. This way a large self-capacitance is formed and high-frequency noise travels through the coil without damping. Fig. 1 presents a hybrid *LC* filter, which contains two isolated foil layers coiled on a core [1–5].

The core material is air to ensure good high frequency properties, but can also be ferromagnetic. The main foil is placed between the PWM device and load. The auxiliary foil is introduced between the turns of the main foil and is connected to a neutral point. This way, there is a remarkable capacitance between the main and the auxiliary foils. Such a system can be described by a simple equivalent *LC* filter circuit in a wide range of frequencies [1–3].

To activate the capacitance between the HLCF layers, the auxiliary foil should be connected to a neutral point: either via Terminal 1 (T1) or via Terminal 2 (T2), as shown in Fig. 2, where L_m and L_a are inductances of the main and auxiliary foils, M is the mutual inductance, C_b is the distributed useful capacitance, C_i1 and C_i2 are the self-capacitances of the main and auxiliary foils, Z_in and Z_out are the voltage source and load impedances.

3. Frequency and time domain measurements

Measurements in frequency domain were provided with HP4194a analyser. Input impedance Z_in = 0.5 Ω and output impedance Z_out = 1 MΩ describe source and load existing in real applications well. The hybrid *LC* filter prototype parameters are as follows: L_m = 126 µH, L_a = 126 µH, C_b = 158 nF, M = 124 µH, C_i1 = 10 pF (estimated value), C_i2 = 150 pF.

Results shown in Fig. 3 indicate that the connection to neutral point at terminal T2 provides much better attenuation than connection to neutral point at terminal T1. This is because the high-frequency currents flow via the capacitance between the foils C_b before they reach neutral point at terminal T2. Vice versa, currents do not use this capacitance if terminal T1 is connected to neutral point. When terminal T2 is connected to the neutral point a resonance at 44 kHz is determined by foil inductance and capacitance between foils C_b.

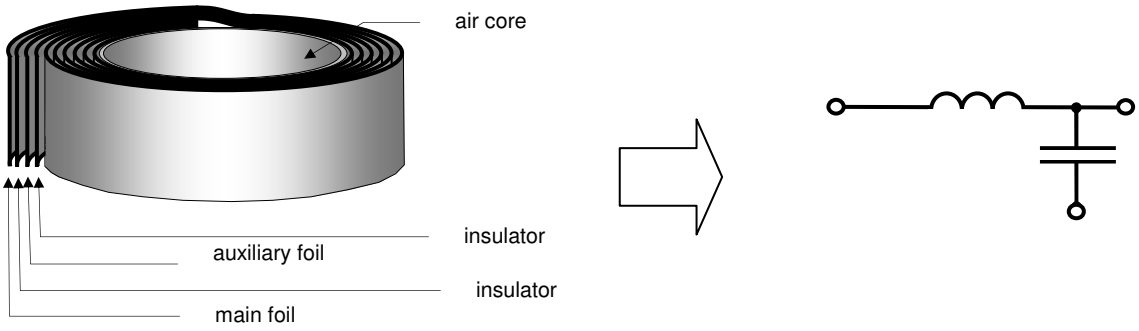

Fig. 1. Single-phase column of the proposed hybrid *LC* filter.

The time domain responses were measured with a 22 kW, 400 V, 3-phase motor driven by an inverter via 90 m cable, which explains overshoots at motor terminals without filter. Again, connection to neutral point at terminal T2 provides the best usage of the HLCF capacitance. Measured 44 kHz oscillations at motor terminals indicate the *LC* nature of the HLCF [3].
When the auxiliary foil is connected to neutral point at terminal T1, voltage waveforms at motor terminals are close to ones measured without auxiliary foil, i.e. HLCF in this case is similar with a typical inductor.

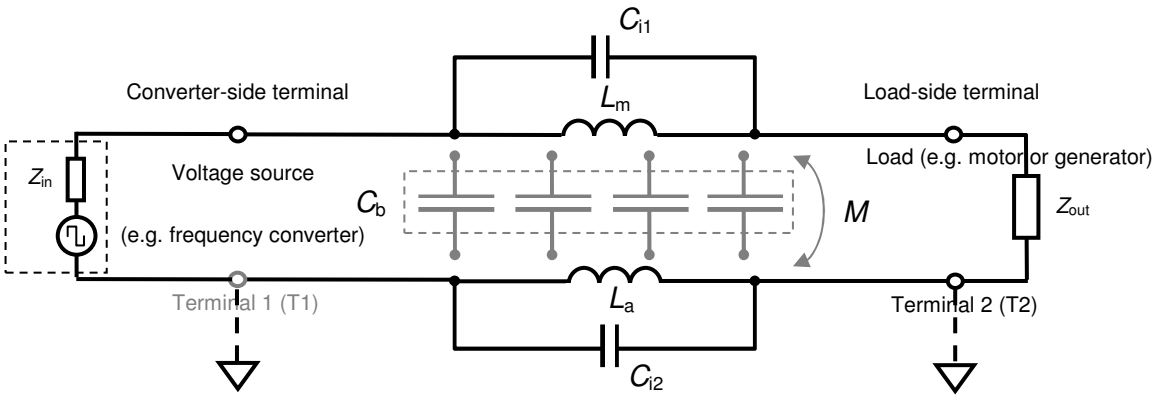

Fig. 2. Lumped presentation of the hybrid *LC* filter.

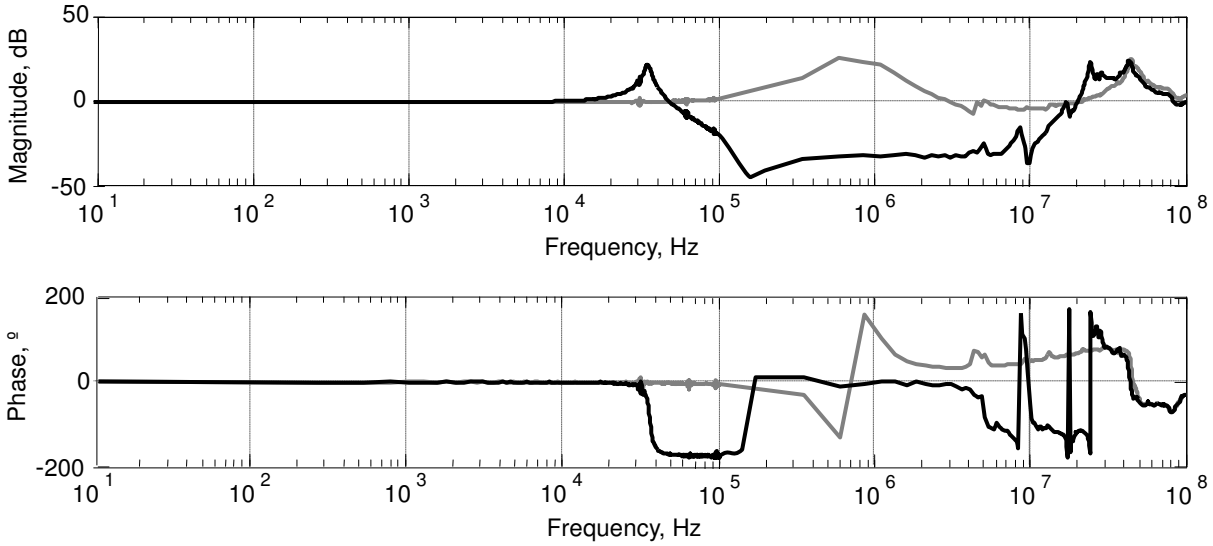

Fig. 3. Frequency responses of HLCF: ▬ – Terminal 1 earthed, ▬ – Terminal 2 earthed.

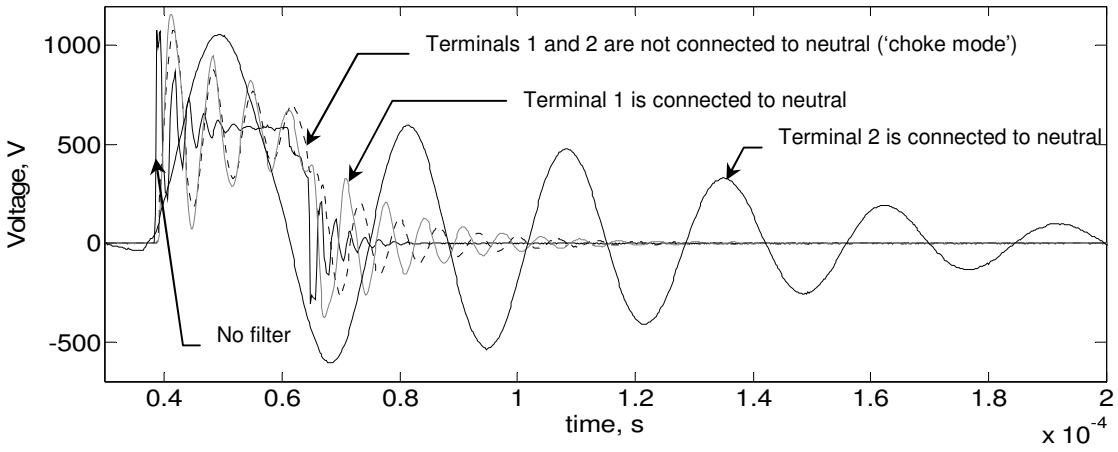

Fig. 4. Time domain measurements of the hybrid *LC* filter.

4. Conclusion

This paper introduces a new hybrid *LC* filter. Due to improved high-frequency behaviour, such a filter is particularly suitable for modern applications where PWM is used, for example, power drives. Constructively, hybrid *LC* filter is similar with the traditional foil inductor, except the auxiliary foil integrated between the main foil turns. Thus, internal stray impedances in this filter are effectively cancelled. Moreover, a large useful capacitance between main and auxiliary foils is formed.

Current paper discovers how the earthing possibilities of the auxiliary foil affect the performance of the hybrid *LC* filter. Measured results in frequency and time domains are presented in the paper. Responses indicate that the best usage of the auxiliary foil can be achieved if it is connected to neutral point at the terminal, which respects to the terminal of the main foil connected to a load.

5. Literature

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