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THE EXTRA L OPPOSED CURRENT CONVERTER

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Abstract. In existing half/full-bridge high precision amplifiers the main output distortion is caused by the required switch blanking time. The OCC topology does not require this blanking time but has a much higher total inductor volume compared to the half-bridge. In this paper a new patent pending topology is introduced that has the advantages of the OCC but with a much lower total inductor volume. The basic operation and properties of the ELOCC topology are explained including an optimization for the total inductor volume and an average model for control design. A prototype high precision current amplifier has been developed with this topology. The behaviour of this prototype is in good agreement with the obtained simulation results.

INTRODUCTION

The half-bridge with output filter is a basic electronic building block used in high frequency switching power converters and amplifiers. This topology however has some inherent problems that limit the performance. Consequently the usability is reduced in high precision amplifiers for high precision positioning using voice coil actuators.

Because two switches are connected in series across the bus voltage only one of the switches can be switched on at a time, otherwise there is a short circuit across the bus voltage. Due to the finite switching time of a transistor a blanking time (dead time) is required between switching off a transistor and switching on the opposite transistor. The dead time must be sufficiently large to ensure that there is never an overlap in conduction of both switches. During the dead time the output voltage is dependent on the load current and current ripple in the filter inductor, resulting in a significant increase of the total harmonic distortion in the output current and voltage.

There exists a topology that does not exhibit this dead time distortion. This power converter topology is the opposed current converter (OCC) [1], [2], shown in Figure 1. In the OCC the bidirectional half-bridge is replaced by two separate unidirectional switching legs with a filter inductor. Unfortunately an OCC has a much higher volume and higher cost of implementation. Methods are proposed to reduce the volume by coupling of inductors [3], [4] or using a split-wound inductor [5].

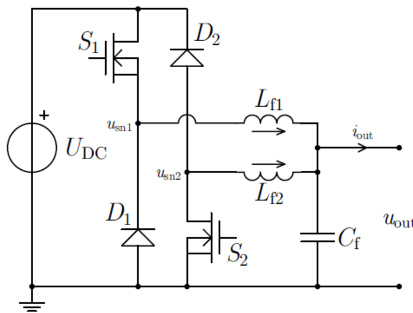

Figure 1: Opposed current converter

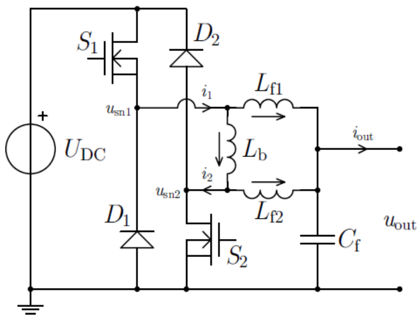

Figure 2: Extra l opposed current converter

In this paper a new topology is proposed with a lower total inductor volume but without the use of coupled inductors. The new topology is named the extra L opposed current converter, or ELOCC and is based on the existing OCC. The ELOCC, shown in Figure 2, has no dead time distortion, resulting in an ultra-low total harmonic distortion (THD) compared to a half/full-bridge amplifier. Because of the unidirectional nature of the switching legs the parasitic diode in the MOSFET is never conducting current resulting in lower switching losses and reduced EMI.

EXTRA L OPPOSED CURRENT CONVERTER

The ELOCC topology is based on the existing OCC topology in which two filtered unidirectional switching legs together can provide bidirectional output current flow. In the OCC, in case the output current i_{out} is positive, the positive leg and filter inductor L_{f1} supply the output current. In case of a negative output current, the negative leg and filter inductor L_{f2} supply the output current. Therefore, both filter inductors should be capable of conducting the full output current. As proposed in [6], in order to avoid non-linear distortions in the output voltage, a biasing current should also be added, flowing from the positive leg to the negative leg to keep both legs in continuous conduction mode (CCM).

In the ELOCC a small extra inductor L_b is added between the two unidirectional legs. The goal of this extra inductor is to balance the current in the filter inductors L_{f1} and L_{f2} such that

(1) $$\langle i_{L_{f1}} \rangle = \langle i_{L_{f2}} \rangle = \tfrac{1}{2} i_{\text{out}} + \tfrac{1}{2} \langle i_{C_f} \rangle$$

where i_{out} can flow in both directions. The brackets ⟨⟩ indicate the periodic average over a switching period. The filter capacitor current i_{Cf} is small compared to the output current and therefore omitted. To balance the filter inductor currents the current through L_b should be controlled such that

(2) $$\langle i_{L_b} \rangle = \begin{cases} \tfrac{1}{2} i_{\text{out}} & \text{for } i_{\text{out}} \geq 0 \\ -\tfrac{1}{2} i_{\text{out}} & \text{for } i_{\text{out}} < 0 \end{cases}$$

which in term can be simplified to

(3) $$\langle i_{L_b} \rangle = \frac{1}{2} |i_{\text{out}}|$$

An offset current flowing from the positive leg to the negative leg is desirable. This offset current can also flow directly through the added inductor L_b, resulting in a desired current

(4) $$\langle i_{L_b} \rangle = \frac{1}{2} |i_{\text{out}}| + i_{\text{offset}}$$

The currents in the converter, when assuming all inductors ideal and large, are shown in Figure 3. The output current in this example is sinusoidal with a peak value of 10A. The converter is operated with a modulated bias current with an offset current i_{offset}=3A. The current in the filter inductors is plotted as L_{fk} where k denotes L_{f1} and L_{f2}.

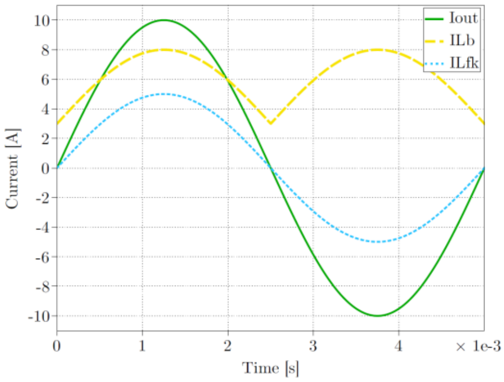

Figure 3: ELOCC Ideal current waveforms

EXPERIMENTAL RESULTS

Measurements are performed on a prototype to verify the functionality and performance of the ELOCC power topology. The prototype is a 360VDC 12.5A MOSFET current amplifier switching at 190kHz. The used filter inductors are 220µH 8Apk with a bias inductor of 33µH 9Apk. The measurement set-up is shown in Figure 4.

The low frequency behaviour is shown in Figure 5 where a 200Hz sinusoidal output current is generated with a peak value of 12.5A. Verification with the simulated waveforms of the converter show that the observed behaviour is in very good agreement.

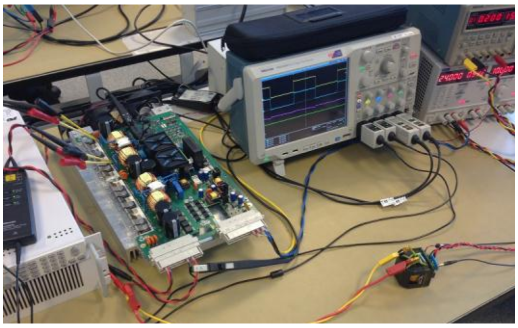

Figure 4: Experimental setup

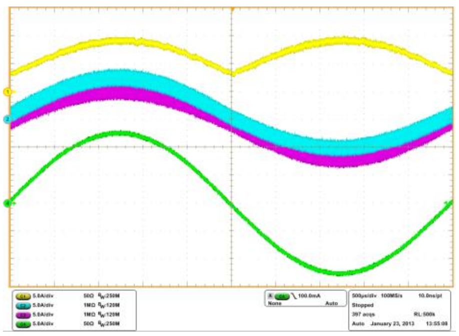

Figure 5: Converter waveforms, Yellow(1)=i_{Lb}, Blue(2)=i_{Lf1}, Pink(3)=i_{Lf2}, Green(4)=i_{out}.

CONCLUSIONS AND FUTURE WORK

In this paper a patent pending new high precision amplifier topology is introduced. This high linearity amplifier topology is comparable to the OCC but with a reduced total volume. The final paper will also include; a more detailed description of the converter operation, a theoretical method for optimizing the total inductor volume and a small signal model for control. Future work includes verification of the converter output linearity.

REFERENCES

[1] N. R. Zargari, P. D. Ziogas, and G. Joos, "*A two switch high performance current regulated DC/AC converter module,*" Proc. Conf Industry Applications Society Annual Meeting Record of the 1990 IEEE, 1990, pp. 929-934.

[2] G. R. Stanley and K. M. Bradshaw, "*Precision DC-to-AC power conversion by optimization of the output current waveform-the half bridge revisited,*" IEEE Trans. Power Electron., vol. 14, no. 2, pp. 371-380, 1999.

[3] J. M. Schellekens, J. L. Duarte, H. Huisman, and M. A. M. Hendrix, "*Volume reduction of opposed current converters through coupling of inductors and interleaved switching,*" in Proc. IECON 2012 - 38th Annual Conf. IEEE Industrial Electronics Society, 2012, pp. 852-857.

[4] Z. Yao and G. Hu, "*Comparison of dual-buck full-bridge inverter with different inductor structures,*" in Proc. Asia-Pacific Power and Energy Engineering Conf. (APPEEC), 2011, pp. 1-3.

[5] C. Chapelsky, J. Salmon, and A. M. Knight, "*High-quality single-phase power conversion by reconsidering the magnetic components in the output stage—building a better half-bridge,*" IEEE Trans. Ind. Appl., vol. 45, no. 6, pp. 2048-2055, 2009.

[6] J. M. Schellekens, J. L. Duarte, H. Huisman, and M. A. M. Hendrix, "*High-precision current control through opposed current converters,*" in Proc. 2011-14th European Conf. Power Electronics and Applications (EPE 2011), 2011, pp. 1-10.