Active Control of Common Mode EMI in Power Inverters
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Research context and motivation
• The switching noise generated in the power section of three-phase inverters gives rise to common mode (CM) conducted emissions.
• Usually, these CM currents are attenuated adding filters at the PCB level, but they are expensive, heavy and bulky.
• The challenge in producing smaller and lighter electronic systems is actually one of the most important problems to address, especially in automotive field.
• This work aims to develop a new closed loop technique able to reduce the CM conducted emission, using software solutions, rather than hardware ones.
• Other software EMC reduction technique already exist, like slew rate control and waveform shaping, but they have many drawbacks on the circuit efficiency, unlike the proposed one.

Addressed research questions/problems
• The research activity target application is an inverter used to drive a BLDC motor. Such motor is controlled by three trapezoidal waveforms, shifted in phase by 120 degrees.
• The generation of CM emissions is mainly due to the high frequency current injection in the parasitic capacitances between the inverter board and the ground plane. Specifically, the output nodes of the inverter show high slew rate signals, which are the main responsible for the current injection in the parasitic capacitances.
• In order to reduce the generation of this HF current it is possible to use a bipolar PWM to drive the motor. Given that only two legs are active at a time, the current injected in the first node parasitic capacitance is recovered by the second node one, and vice versa.
• However, the output voltage waveforms however are not complementary one another, since some delay (τd), due mainly to the drivers, is present between the waveforms at the two active output nodes. This delay generates CM currents. So, in order to eliminate these currents, the two output waveforms should be aligned.
• In order to define the relation between the time delay and the CM emission an analytical model has been developed. Moreover, Spice simulations have been carried out in order to compare the proposed technique with the Spread Spectrum Modulation (SSM). The proposed technique reduces the CM emission 10 dB more than SSM up to 24 MHz, with the aligning accuracy that can be reached by commercial microcontrollers. Over this frequency the two reduction techniques show similar performances.

• Some preliminary EMC measurements on an inverter, aligning manually the output waveforms, have been carried out, confirming that the CM disturbance spectrum is reduced when the output waveforms are aligned. The attenuation magnitude reaches -15 dB [5].
• Given that the value of τd has an high uncertainty and it could vary during the inverter operation, a feedback control system is needed to ensure the minimum CM EMI generation in every working condiion.

List of attended classes
• 01NOINC – Controllo Digitale di Convertitori e Azionamenti (2017, 6 credits)
• 01RLPVR – Advanced control in electrical energy conversion (2017, 4 credits)
• 02LDHRV – Communication (2017, 1 credit)
• 08XTFR – Project management (2017, 1 credit)
• 01RSVP – Public speaking (2017, 1 credit)
• 01QORRV – Writing Scientific Papers in English (2017, 3 credits)
• 02CHHRV – The new internet society: the black box of digital innovation 1 (2017, 1 credit)
• 01SEHRV – Managing PhD thesis as a project (2017, 2 credits)
• 01LCPU – Experimental modeling: costruzione di modelli da dati sperimentali (2018, 6 credits)
• 02TRTV – Generatori e impianti fotovoltaici (2018, 5 credits)
• 01SFVRV – Programmazione scientifica avanzata in Matlab (2018, 4 credits)

Submitted and published works

Adopted methodologies
The CM voltage at the inverter output can be expressed considering the two active nodes. For instance, when the U and V outputs are switching, the CM voltage is:
\[ V_{CM} = \frac{V_U + V_V}{2} \]
This voltage is the superposition of a DC component equal to one half of the power supply, and some voltage spikes dependent on the delay. These spikes are the responsible of the CM EMI sensed by the LISNs.
The amplitude of these voltage peaks is proportional to the value of τd when the delay is lower than the rising/falling time:
\[ V_{CM,peak} = \frac{V_{DD}}{2} \]
When τd > t, this voltage saturates at \( V_{DD}/2 \). This peak value can be measured and therefore the delay can be compensated acting on the PWM parameters.

The filter output voltage is given as input to two envelope detectors, one for the positive peaks and one for the negative ones. The peak is therefore sampled by two independent ADC channels of the microcontroller.

A control state machine algorithm modifies the PWM phase and duty cycle parameters, with a resolution of around 1 ns, in order to align the output waveforms.

From mixed signal simulations performed on the system it turns out that the CM disturbance is significantly attenuated when the EMI control system is activated. This can be seen both from the time domain signal and from the measured spectra at the LISN outputs.

Novel contributions
• In this research activity the generation of the conducted CM emissions has been analyzed in detail, with analytical models including the time delay effect on EMIs.
• The technique has been applied on a three phase system driving a BLDC motor. It has been verified by measurements that, driving a BLDC motor, a proper alignment of the output waveforms can reduce significantly the CM disturbance level.
• A novel system, able to reduce in closed loop the CM EMI, has been designed. This system is composed of a low cost network and a software algorithm able to align the output waveforms. The proposed technique does not affect the system efficiency.
• The effectiveness of the system has been verified through electrical and mixed signal simulations.

Future work
• The designed and simulated closed loop CM reduction system will be prototyped and tested on an automotive application.
• Since SSM and signal aligning technique act with two different and uncorrelated principles, it would be possible to employ both the software EMI reduction techniques to get better performances.