Behavioral Model for Common Mode Filter and Performance Optimization Aspects

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Abstract

A well designed common mode filter for motor drive application can significantly improve the level of electromagnetic interference generated by the cable and the motor housing. The subsequent design of this filter is strongly dependent on the actual in situ parameters of the motor drive and often leads to a "cut and try" process. To simplify this process a novel behavioral model for common mode choke (CMC) is proposed. The model can be used to show the influence of the designable parameters on the final performance of the choke placed in a circuit. The identification of the model uncertainties can be used to evaluate the upper and lower limits of the final attenuation.

1. Introduction

The majority of EMI (Electromagnetic Interferences) concerns are centered on radio frequency (RF) emission sources. Although most RF transmissions are achieved under controlled conditions, it is this transmitted energy that may create an interference which in turn may affect the performance of many electronic devices.

A proper filtering of the frequency converter is a key aspect in the management of the EMI in the overall motor drives. Frequency converter (FC) components generate a high level of electromagnetic interferences on the power lines, motor cables and via radiated electromagnetic field. In the same time filters are designed after the construction of the FC. In the case of passive filtering [1], chokes are designed in a "cut and try" process with significant issues as size, cost and weight [2], [3] .To avoid the construction of several prototypes, often oversized, designers need an analytical method to predict performances of filters.

The following section shows how a properly designed common mode filter can significantly improve the level of the radiated emission in the radio frequency range. In the third section a novel behavioral model for common choke is introduced. This model allows a better management of the noise spectrum. Section four presents optimization and measured results for the proposed model.

2. Effect of a common mode filter on the radiated emission level

The design of a common mode filter resulted in the configuration given in Figure 1. The functional parameters are: direct drive motor, relatively open, in a harsh military environment, 440 V mains supply, ungrounded and no neutral (3 phases only) and 15 kVA power consumption. For the dV/dt filter (series inductors, capacitors between the lines) a commercial of the shelf filter was suitable and applied. The main element is the common mode choke (CMC). The core material is nanocrystalline material with a high saturation level (above 1 T) and a high permeability (at least 25000 up to 100 kHz). For this application 4 cores were needed, assuming a maximum common mode current of 1 A. The CMC as depicted in Figure 2 has the required inductance of 40mH, can conduct at least 35 A and has spreading of les than 1 %. That means that 1% of 35 A, i.e. 0.35 A will be added to the 'unwanted' common mode current. The total common mode current should still be less than 1 A to avoid saturation. It is important to note that during saturation the inductance is decreased drastically, and then resonances and voltage overshoots occur which can damage the motor. For the feedthrough capacitors 4.7 nF was used, because 10 nF appeared to be too high and the frequency converter would go in overload. The radiated emission has been measured inside a (full-) anechoic chamber. In Figure 3 the measured levels is given for the set-up with only the dV/dt filter (top) and for both the filters together (bottom).

3. New behavioral model for common mode filter and its optimization aspect

The table 1 lists the impedances of the common mode choke and their respective designable parameters. The modelling of the turn to turn capacitance and the inter-winding capacitance is detailed in [4], [5]. The value of the CM impedance is strongly related to the value of the permeability of the core. As detailed in [6] the ferrite core introduces frequency variable impedance in the circuit. The core will not affect the lower frequency operating signals but does block the conduction of EMI. In [7] a model is proposed of frequency dispersion of complex permeability in ferrites. The value of the DM impedance is related to leakage inductances, and hence to spaces within the wiring system. For a more accurate estimation, formulae are available in literature [8].

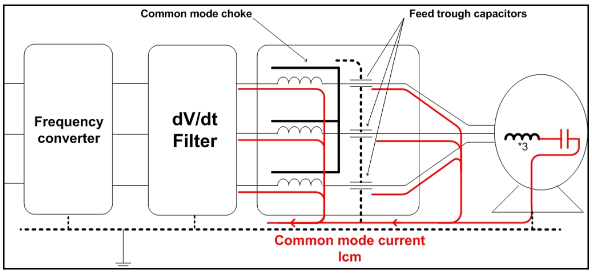

Figure 1: Overview of the filter, with feedthrough capacitors and nanocrystalline inductors

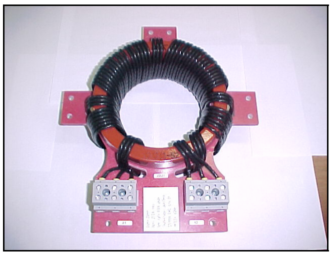
Figure 2: The CMC as applied

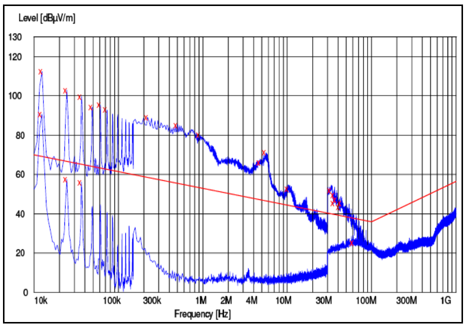

Figure 3: Radiated emission level with only the dV/dt filter, and with the dV/dt filter and the common mode filter

Table 1: Designable parameter for common mode choke

Impedances of the CMC	**Designable parameters**
Z_{cm}	Material (complex permeability) Dimension of the choke Number of turns Effective length
Z_{dm}	Number of turns Dimensions of the choke Angle of leakage inductance
Intra Winding Capacitance And Turn to Turn Capacitance	Number of turns Dimensions of the choke Wire dimensions and materials(isolation and diameter) Length of turns

An overview of the topology of the model in consideration is presented in Figure 4. Figure 5 presents the electrical setups in the case of a frequency converter with voltage regulation. The equivalent circuit of the common choke is represented: *Z3, Z4* and *Z5* are the parasitic capacitances discussed before. *Z1* and *Z2* are a combination of the common mode impedance Z_{cm} and the differential mode impedance Z_{dm}.

The designer will have to provide values of currents and voltages, measured or simulated, where the CMC will be placed later (*i1b, i2b, V1b, V2b* in Figure 5). The value of the impedance seen at this place from the motor, between the two phases (*Ze* in Figure 5) and between one phase and the ground (*Zg* in Figure 5) are also needed. These values in addition of the characteristics of the common mode choke allow evaluation of performances of the CMC with 4 attenuation coefficients.

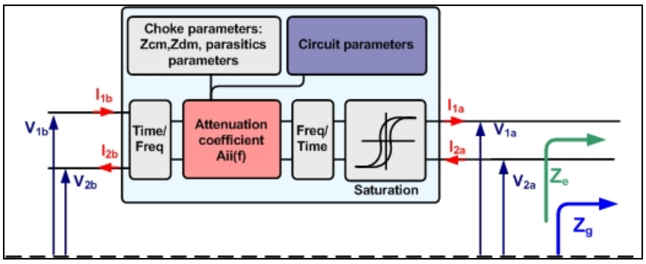

Figure 4: Topology of the behavioral model for CMC

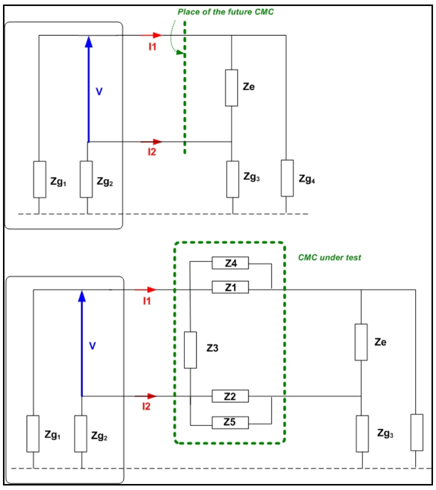

Figure 5: Electrical setups in case of a voltage regulation of the frequency controller

Sensitivity studies will provide additional insight into the behavior of the choke by understanding of how variations of parameters, for instance of elements values, influence the final performance [10], [11]. A local approach is based on a first order approximation and is not suitable for large variations. The local approach will be mainly used to evaluate for instance the effect of the error related to modelling or measurements of impedance. The normalized simplest sensitivity will be used; it is the derivative function F with respect to any parameter h.

4. Results

Measurements have been performed on a common mode choke presented in Figure 6.Its characteristics have been measured with an Impedance/Gain-Phase Analyzer (HP 4194A) between 100Hz and 40 MHz. The core is made of iron powder material (Fe). It may be used as pure inductor up to approximately 200 kHz. The resistive losses dominate thereafter up to approximately 3 MHz as presented in Figure 6. The core is no longer effective in the frequency range above approximately 10 MHz. The core is bonded with a copper wire with a diameter of 0.99mm. Its insulation in polyurethane has a thickness of 12 µm. The rated current is 5A and nominal voltage 250Vac.

The table 4 compares the modeled with the measured impedances values and shows a general good agreement. The figure 7 presents the attenuation coefficients with a variable capacitance to ground. The behavior of these coefficients is mainly driven by three resonances between the three impedances: common mode impedance, turn to turn impedances and differential mode impedances. Figure 8 illustrates the upper and lower limits of the attenuation coefficient for a tolerance of 10%.

5. Conclusion

The design of a filter for frequency converters in a mechatronic product is presented. The work was carried out because commercial off the shelf filters appeared to be inadequate for this application. The design constraints of mechatronic applications limited the design freedom considerably. The constructed filter resulted in a radiated emission level which was near to the noise floor of the measurement equipment.

There is a need for designer for an analytical method to predict performances of the filter. That is why a new behavioral model of common mode chokes performances is proposed: the topology and methods used to model the different properties of the CMC is presented. Its seven impedances are used to evaluate the attenuation coefficients affecting the currents flowing in the initial setup.

Comparisons of evaluated and actual performances of common mode chokes are taken into account. The identification of its uncertainties in the behavioral model is used to evaluate the upper and lower limits of these performances. The designer is thus in a position to design in the first place a filter with a chosen risk of deviation of performances in the final configuration.

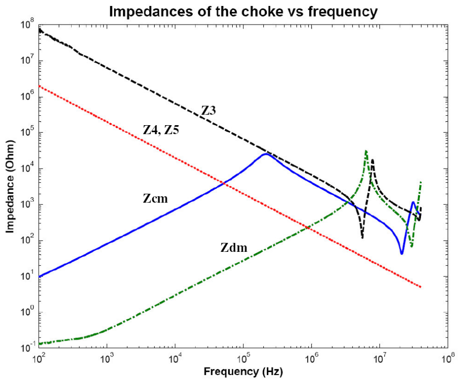

Figure 6: Impedances of the choke vs. frequency

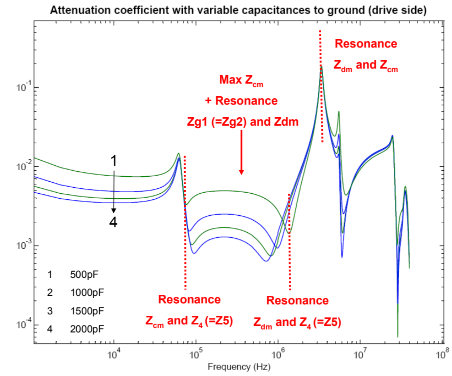

Figure 7: Attenuation coefficient with variable capacitances to ground

Table 4: Parameters of the choke under test

Impedances	Theoretical values	Practical value
CMC inductance	10mH	9.9mH
Leakage inductance	41µH	40uH
Cap. inter windings	Nan	16pF
Cap. Turn to turn	71pF	49pF

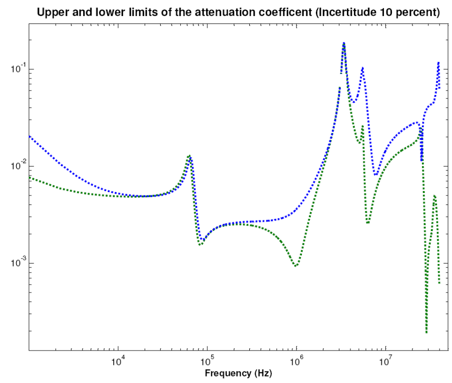

Figure 8: Upper and lower limits of the attenuation coefficient (Incertitude of 10 percent)

6. References

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