

# Common Mode Currents in the Maritime Industry

How Alewijnse implemented oval-shaped nanocrystalline cores for common mode suppression, increasing reliability under all operating conditions.



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# Abstract



Electric ship propulsion systems generally demonstrate a strong trend towards increasing efficiency under all operating conditions. In this specific case, however, the system of electric power generation, distribution and propulsion appeared to be not conforming with all EMC requirements for ships; specifically, current leakages (including the capacitive effect) exceeded limits defined by Lloyd's rules – despite individual components fulfilling the specifications/requirements.

Following analysis of electrical, mechanical and given dimensional requirements and conditions, we developed oval-shaped nanocrystalline cores for common mode suppression, these being consistent with the mechanical and thermal requirements in this given environment. This article presents the requirements, the design of the cores, and the results in terms of common mode currents.



# Introduction

Electrical propulsion is being implemented to reduce both fuel use and the space required, as well as increasing the reliability of the electrical power and propulsion systems. The reliability aspect is an essential requirement for ships with Dynamic Positioning systems (DP) notation such as cable / pipe laying vessels and offshore supply vessels.

Electrical power generation, distribution and propulsion systems are rather complex in terms of EMC because of the special situations in ships compared with common industrial or transportation applications. EMC requirements are defined by IEC 60533 and Lloyd's rules. In our specific case, the electrical components fulfilled IEC standards but the entire system appeared to not conform with Lloyd's rules after finalisation of the electrical system. The challenge was to calculate and introduce supplementary common mode suppression within the limited space available.

# System and problem description

A cable / pipe laying vessel with an electrical propulsion system and with DP AA notation according to Lloyd's Register Society, equipped with:

- 5 (6) diesel-generator sets, generating power at 690V, 60 (50)Hz (typically around 13MW)
- 2 propulsion azimuth thrusters (typically around 6MW)
- 3 bow thrusters (typically around 4MW)
- 1 stern thruster (typically around 1MW)

A part of the electrical power generation and distribution system and electrical propulsion system is shown in fig 1. The AC system is an IT power network system. The Variable Frequency Drive (VFD) with active rectifier (Active Front End, AFE) is directly connected to a 690 VAC Main Switch Board (MSB) and a 690 VAC electrical power distribution network. An active Front End has some advantages over conventional 12-pulse or 24-pulse (Diode bridge) VFD systems. These include a reduction of the THD level, a transformer is not essential, it requires less space, etc. In our case, the active rectifier is realised with IGBT switching elements with a typical switching frequency of 1.5kHz.

The design of electrical power generation systems and electrical propulsion systems in relation to the EMC aspect must comply with IEC 60533 and Lloyds rules (6.4 Protection against earth faults).

The following EMC zones are specified according to IEC 60533:

- Deck and bridge zone
- Accommodation zone
- General power distribution zone
- Special power distribution zones

Electrical propulsion systems including VFD are placed in the Special Distribution zone. There, there is no specified maximum level of radiated and conducted emissions as there is in the other three zones. Therefore, the supplier of the Active Front End has no obligation to reduce the maximum levels of these emissions. In particular, the VFD does not have a common mode filter as a standard component. Usually, this situation is specified in contracts as the responsibility of the system integrator. On the other hand, according to Lloyd's rules, (6.4 Protection against earth faults), every distribution system having a specified connection to earth must be provided with a means to continuously monitor and indicate the current flowing through the earth connection which is limited to  $5_{A_{rms}}$ .

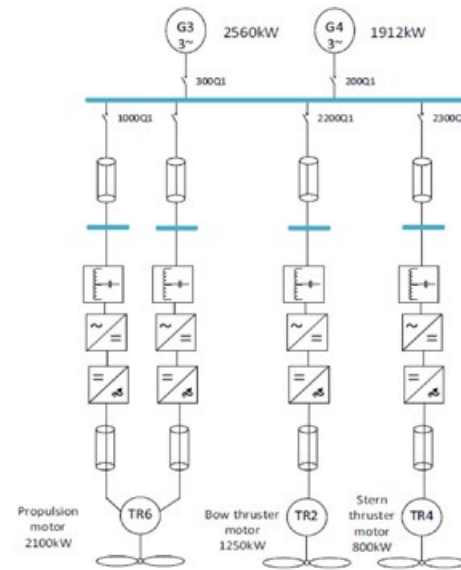


Fig. 1: Part of considered electrical power system. The components in the red frame are shown in fig. 2.

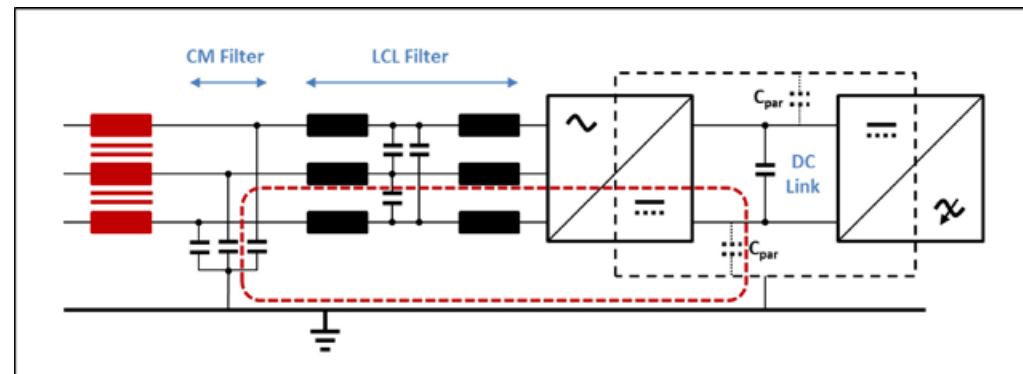


Fig. 2: Detail of fig. 1: Configuration of Active Front End with different filters and desired common mode current (red dash)

In the design of electrical installations for ships, the proper determination of cable routing, cable selection and cable segregation is essential in relation to the above requirements. In the design of VFD cabinets for the electrical propulsion system, additional components acting as a high frequency earthing system, such as the EMC rail, common mode filter etc. must be implemented in relation to the above mentioned requirements. In electrical design, however, it is not possible to cover all risks in relation to common mode phenomena. Therefore, during commissioning it is necessary to measure the level and frequency spectrums of common mode currents.

The switching process in IGBT generates via DC link (as source) common mode voltage (noise) typically between 20kHz and 1MHz, in our case mainly between 50 and 200kHz. The corresponding current mainly flows through the PE rail and back to the DC link. However, a part of the common mode current follows a parasitic path via the hull back to the generator and via MSB back to the drive terminals. Besides the general problem regarding Lloyd's rule, generators suffer from this current which reduces their lifetime. All common mode currents mentioned in this article were measured at the generator cables close to the generator (see fig. 1).

During the installation of VFD cabinets, additional common mode filters (see fig. 2, they are not a standard component in VFD), are implemented at the input of the AFE. They consist of capacitors only and are connected via the star point to the PE rail of the drive cabinet to route the common mode back into the DC link (red path in fig. 2, ICMC2 in fig. 3). The lower the impedance path of the filter, the less is flowing to the main distribution (ICMC1 in fig. 3). The installation aspects of the filter have a big impact on the efficiency of the filter.

For this project, the common mode filter was built into the drive cabinet. This resulted in an expected reduction of common mode currents, but still higher than 5Arms in some operational configurations (see table 1). Additional measures (components) were needed to reduce the common mode to acceptable levels in line with class requirements.



# Technical solution

The implementation of cores around the power supply cables linking the Main Switch Board and the drive cabinet of the Active Front End (AFE) was obviously one of the technical solutions considered. The goal is to increase high frequency impedance (inductive resistance  $X_L$ ) on the path to the MSB, and to keep the common mode currents inside the VFD cabinet. The cores around the cables form a common mode choke with 1 turn per phase. In principle, a low pass filter towards the MSB is formed by the existing common mode filter and the core.

To select the right cores, analysis of the current situation and simulations of different options are essential. A vital aspect of developing this solution is the measurement of the common mode level and frequency spectrum for different configurations of the electrical plant (selected results in table 1). The measuring plan and definition of measuring points are part of this process. The results have been used as inputs for the technical specifications of the cores. For this specification, the following aspects have been considered:

- Available mechanical space in drive cabinet
- Common mode level and frequency spectrum
- The relationship between inductance and frequency  $L(f)$
- The relationship between inductance and bias current,  $L(IDC)$
- Ship electrical power network impedance
- Ship power network resonance frequency

Some parameters of the cores were defined using the MathLab Simulink tool. The same model, using test results of actual cores, was used to estimate the influence of the cores on the common mode level. Test results of sample cores included  $L(f)$  and  $L(IDC)$  measurements.

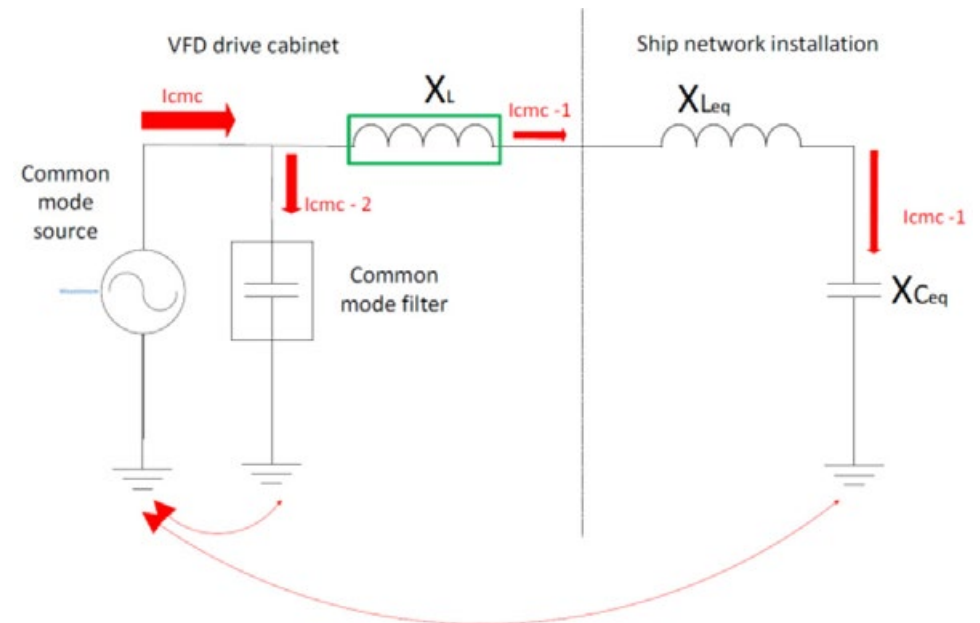


Fig. 3: Principal schema of common mode currents in the system

# Properties of cores

Cores for suppression of these common mode currents must fulfil a number of requirements:

- Because of limited space (fig. 5), high impedance within a small volume, i.e. high permeability
- Due to a rather high common mode current and limited space (resulting in maximum magnetic path length), an upper limit to the permeability / saturation induction ratio is needed to avoid saturation
- Due to the high flux swing, resulting from the previous considerations, and medium frequencies with higher harmonics: low losses are required
- High resilience against mechanical influences like vibrations and pressure due to assembling
- Thermal resilience and low ageing

As a result, nanocrystalline cores appeared to be the optimum solution.

Fe-based amorphous cores have higher saturation induction ( $BS = 1.56T$ ), but are not appropriate for high impedance in the used frequency range. When impregnated (see below), the permeability decreases to a few thousand due to high magnetostriction, and losses become too high. Finally, the high saturation induction can't be used, and impedance is small.

Ferrites, although being the optimum solution for many CMC applications, provide too low saturation induction ( $BS = 0.3-0.45T$ ), leading in our case to huge sizes which cannot be produced or accommodated in the available space (fig. 5). Moreover, ferrite or even powder cores are expected to not be resilient enough against mechanical strain given the core size.

Powder cores or laminated steel do not provide enough impedance in the given volume.





The core size was designed according to the space and assembling conditions. Finally, we used three types of extreme oval cores with total lengths of about 350-400mm and total widths of 100-170mm, matching the cabinets already being mounted in the ship. The upper permeability to avoid saturation considering this core size was calculated to be around 50,000, which was also an appropriate value for materials' permeability under these conditions.

For the cores we used VP500 material VACUUMSCHMELZE® (BS = 1.2T,  $\mu$  adjustable between 20.000 and 150.00 for linear B-H-behaviour). The cores were manufactured by us according to the desired initial permeability of about 30,000. Thereafter, they were wrapped with glass fibre tape and impregnated with Epoxy resin to achieve sufficient mechanical and thermal robustness.

After impregnation, initial permeability decreased to about 15.000 - 20.000 due to non-zero magnetostriction, which is not achievable for this large core volume. On the other hand, the expected degradation of linear hysteresis loop results in softer transition into saturation which also helps to suppress unexpected common mode current peaks. As shown in fig. 4, the AL value is still about 40% of initial value at highest observed common mode currents (around 15A peak) without suppression cores, which is acceptable/within reasonable limits (see below).

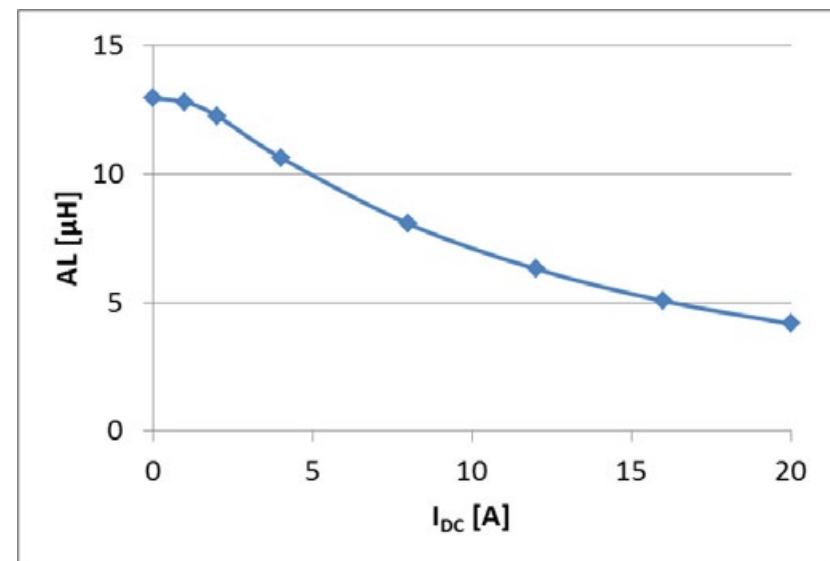
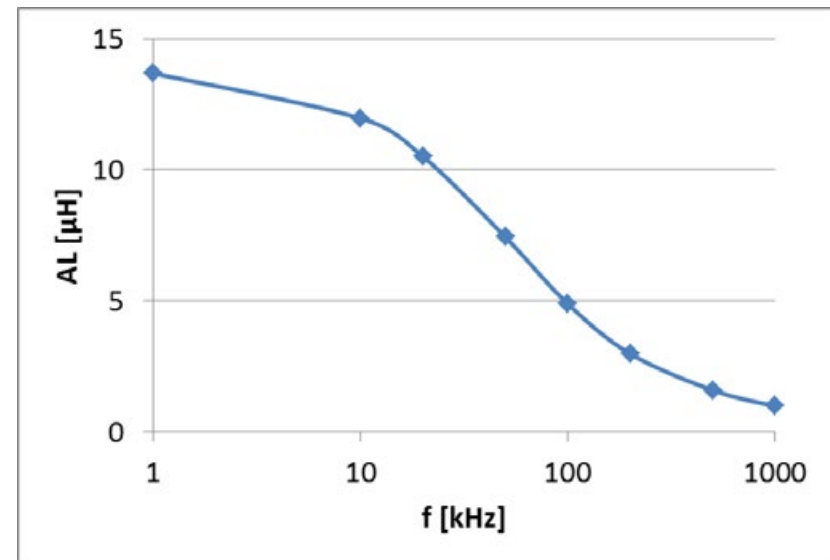


Fig. 4: AL-Value of a typical core (mean magnetic path length = 810mm, magnetic cross section = 560mm<sup>2</sup>, weight 3.4kg) depending on frequency (top) and DC-bias current (bottom, f = 5kHz) showing the saturation behaviour.

# Results

Cores in different sizes according to spatial conditions have been manufactured and assembled within the drive cabinets (fig. 5). In table 1, values of the common mode currents entering the generator before and after the implementation of the cores are shown. The table shows only three specific configurations of the electrical plant. Generally, the analysis of the common mode currents was done for all 44 different configurations.

After implementing the cores, the maximum level of common mode measured in one specific configuration was 3.1 Arms. All common mode values, which were measured during the last measuring campaign, satisfied class requirements for all 44 different configurations.

No. of AFE drives online	Without cores		With cores	
	Frequency [kHz]	Max. $I_{CM1}$ [ $A_{rms}$ ]	Frequency [kHz]	Max. $I_{CM1}$ [ $A_{rms}$ ]
0	60 - 180	0.035	0 - 212	0.315
2	70 - 100	6.2	0 - 212	2.94
4	80 - 110	8.2	0 - 212	2.84
6	80 - 110	9.2	0 - 212	2.26

*Measurement results before and after implementation of the cores. Frequency indicates the range with significant excitation; common mode current has been measured in this range.*



*Fig. 5: two assembled cores in the cabinet*

# Conclusion

The implementation of Active Front End in Electrical Propulsion systems requires more attention in electrical design and commissioning process in relation to EMC requirements. Therefore, electrical cable installation, measuring of common mode levels (including frequency spectrum), power network analysis and, if possible, simulation of the entire system, is necessary before commissioning.

Supplementary implementation of cores for suppression of common mode currents is possible and has been successfully demonstrated. It is, however, a complex process considering different operational configurations and the limited space available.



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