The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 2025

Volume 38, Pages 12-19

IConTES 2025: International Conference on Technology, Engineering and Science

Electromagnetic Interference (EMI) in Variable-Speed AC Electric Drives: Mechanisms and Solutions

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Abstract: This study investigates the electromagnetic compatibility (EMC) performance of a variable-speed drive (VSD) system in industrial applications, where managing electromagnetic disturbances is crucial for reliable operation. The analysis is structured in two main parts to provide a comprehensive evaluation of the system's behavior. The first part focuses on characterizing electromagnetic interactions within the complete system by examining electromagnetic disturbance (EMD) spectra and identifying common-mode (CM) propagation paths. A spectral assessment of conducted disturbances enables a detailed understanding of coupling mechanisms, the identification of propagation pathways, and an evaluation of the associated conducted emission risks. This step is essential for determining potential sources of interference and implementing suitable mitigation techniques. The second part quantifies conducted emissions injected into the electrical network, which can affect the performance of surrounding electronic equipment. The proposed model is applied in a structured approach to analyze and mitigate electromagnetic disturbances, with an emphasis on evaluating common-mode current propagation and assessing the influence of individual VSD system modules on EMD generation. To ensure accurate results, various testing conditions and configurations are considered. High-frequency (HF) spectral analysis is conducted over the 50 kHz – 30 MHz frequency range, in compliance with EN 55022 (Class A) normative requirements, ensuring adherence to industry standards and improving system robustness.

Keywords: Electromagnetic compatibility, Electromagnetic interference, EN55022 standard, Variable-speed AC electric drives

Introduction

Several studies have emphasized the importance of accurately characterizing high-frequency (HF) behavior in power electronic systems (Mohammed et al., 2024), (Mohamed et al., 2012), (Sara et al., 2023) to manage

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

electromagnetic interference (EMI). HF components in isolating transformers (Miloudi et al., 2019) and switching devices like MOSFETs and IGBTs significantly impact EMI generation (Benhadda et al. 2020), (Lahlaci et al. 2025). Research on SMPS and DC/DC converters highlights the need to analyze both common-mode and differential-mode emissions using spectral techniques (Lahlaci et al. 2025), (Naima et al. 2024). Predictive models also assist in assessing conducted disturbances early in the design process, supporting the development of EMC-compliant systems (Gourbi et al. 2024). All equipment, for its operation, is necessarily connected to the environment, to other equipment, to a power source and to earth. In the absence of special precautions, these links represent access paths for undesirable disturbances. Interactions due to conduction can be suppressed by the use of filters whose role is to allow only the desired signals to pass (Jon et al., 2021; Li & Fei, 2021).

The filters attenuate interference signals according to their frequency independently of their amplitude. Filters are characterized either by their transfer function (Houcine et al. 2022), (Miloudi et al. 2010), or by their loss of insertion (Zeghoudi et al. 2022). The efficiency of the filter translates the insertion losses; it depends on the impedances of the load and the source between which the filter is positioned. For the reduction of conducted emissions, we can cite two methods, the first being filtering by passive elements, and the second being the use of active filters (Yongbin et al., 2016; Miloudi et al. 22014; Bermaki et al. 2023). In this work, we are going to present the existing means of reducing disturbances at the input of the variable speed drive by inserting a passive filter.

Common Mode Filter of the Variable Speed Drive System

A passive filter is characterized by the exclusive use of passive components used to reduce conducted disturbances (Abdelhakim et al., 2022), (Zeghoudi et al., 2022). These filters do not require a power supply. This technique makes it possible to advantageously modify the propagation path of the disturbances in order to hinder their circulation (Miloudi et al., 2023), (Miloudi et al., 2025). The filters can be placed upstream (mains side), or downstream of the drive (motor side).

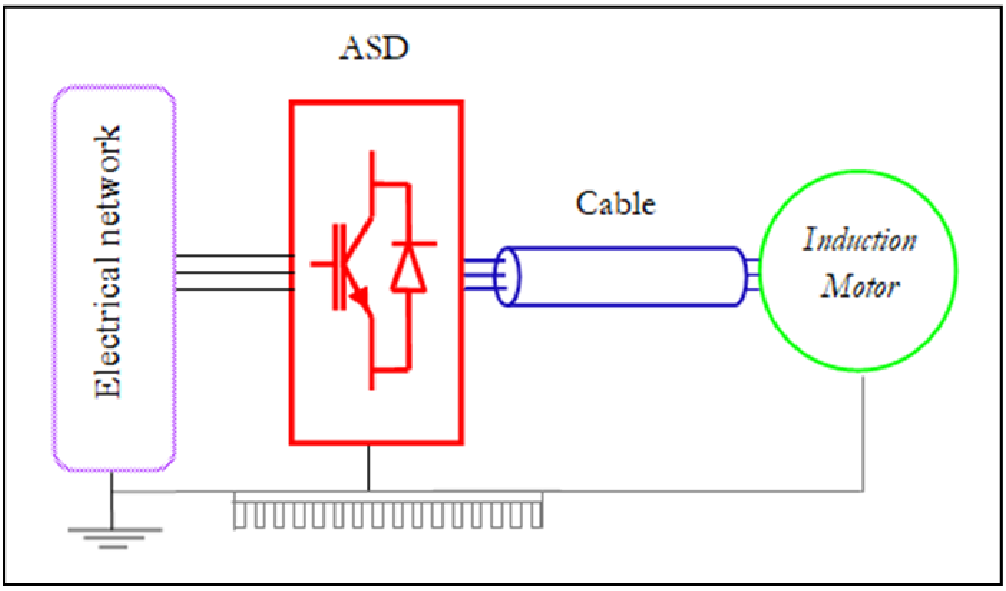

Figure 1. Adjustable speed drive structure

In this configuration (Figure 1), the filter is imposed in front of the network; this technique is widely used by the new generations of variable speed drives. The combination of high impedance (inductance) and low impedance (capacitance) paths makes it possible to direct disturbing currents along paths that do not disturb the network. This type of filter is particularly effective for the normative aspect. But unfortunately, there is no action on the motor overvoltage, and also it does not make it possible to reduce the common mode currents circulating in the motor.

EN 55022 Standard

This standard, specifying high frequency levels of conducted emissions applicable to residential, commercial and light industrial areas. Standards specifications for conducted disturbances in the radio frequency band (150 kHz – 30 MHz) fall into two categories (Figure 2). The first, referred to as "Class A", defines the emission level for devices intended for the industrial sector. The second, and certainly not the least, is reserved for the domestic and hospital sector: it is: Class B. The levels are given on a logarithmic scale in dBµV (Michał & Jan, 2022), (Satish & Jhansi, 2018).

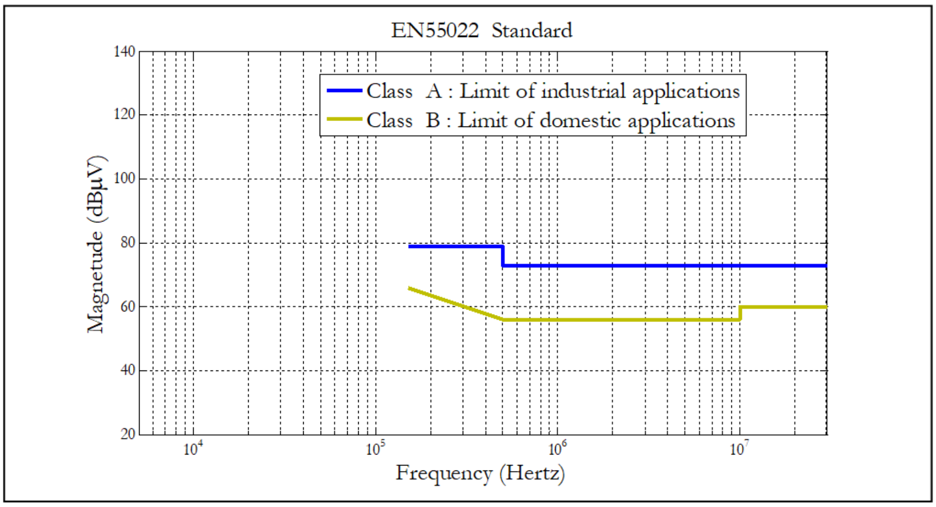

Figure 2. Levels of conducted disturbances set by standard EN 55022

As portrayed in Figure 2, the limit is quite stringent for Class B than Class A, Class A being a somewhat relaxed limit. Generally speaking, designers of electrical equipment make an effort to comply with the Class B requirements so as to allow the wider marketing of their equipments. In cases where this is not required, they may opt merely for Class A being less stringent because it involves lesser filtering requirements. As part of the study of conducted disturbances, the various experimental setups and devices used to measure conducted emissions include: the Line Impedance Stabilization Network (LISN), voltage and current probes, and the spectrum analyzer.

The LISN is equivalent to a filter inserted between the power supply network and the input of the equipment under test. It has multiple functions: it isolates the equipment under test from the power network, sets the prescribed impedance at the measurement points, and channels the conducted disturbances toward the measuring receiver. Through these various tasks, the LISN ensures the reproducibility of the measurements. There are several types of LISN structures, each defined by the standard relevant to the application domain. A common feature of all structures is the equivalent impedance, which ranges from 5–10 kHz up to 50–30 MHz. The diagram of the LISN is shown in Figure 3.

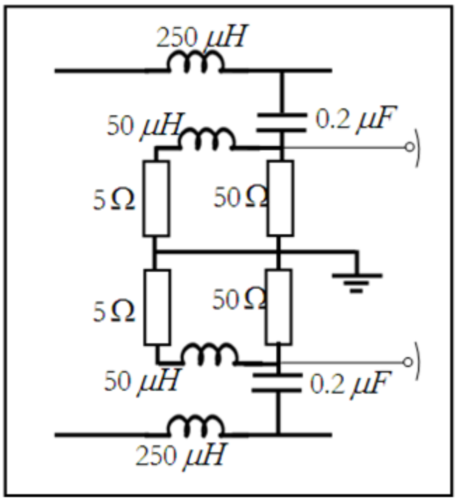

Figure 3. Simplified structure of the LISN

Method

EMC Filter

A proposed EMC filter is composed exclusively of passive components, used to attenuate conducted disturbances. It does not require any external power supply. This type of filter works by advantageously modifying the propagation path of disturbances in order to impede their flow. The filter is generally placed upstream, that is, on the power supply side, before the input of the equipment to be protected.

In this study, the proposed solution consists of adding an EMC filter mainly composed of an inductor and a capacitor. The combination of high-impedance paths (inductor) and low-impedance paths (capacitor) allows disruptive currents to be diverted along routes that do not disturb the network. The EMC filter is characterized by its transfer function, given by the relation.

$$Z = j * L * w + \frac{1}{j * C * w}$$

The purpose of which is to circulate the PEMs generated by the converter as little as possible outside of it, this filter will be placed between the Line Impedance Stabilization Network (LISN) and converter input (Figure 4).

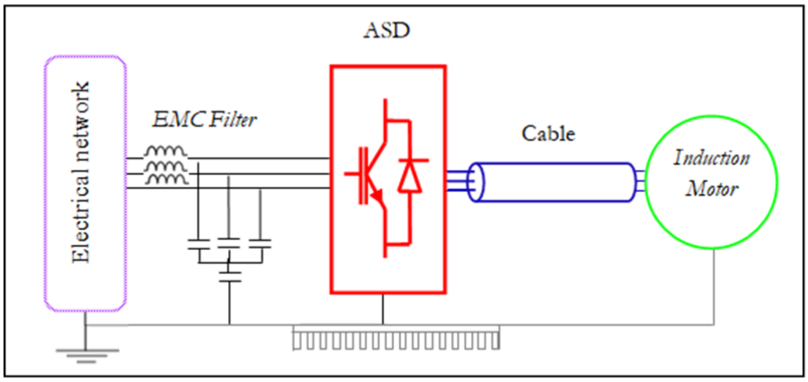

Figure 4. Common mode filter on input of ASD

In the problem of optimizing EMC performance, taking EMC constraints into account results in a comparison of the level of emissions (envelope of the spectrum) input of the variable speed drive, with respect to the limit imposed by the standard EN55022 for the corresponding frequency. This study's optimization strategy aims to reduce electromagnetic emission levels that exceed the EMC standard thresholds, ensuring compliance across the entire applicable frequency spectrum specified by the standard. The optimization flowchart is shown in Figure 5.

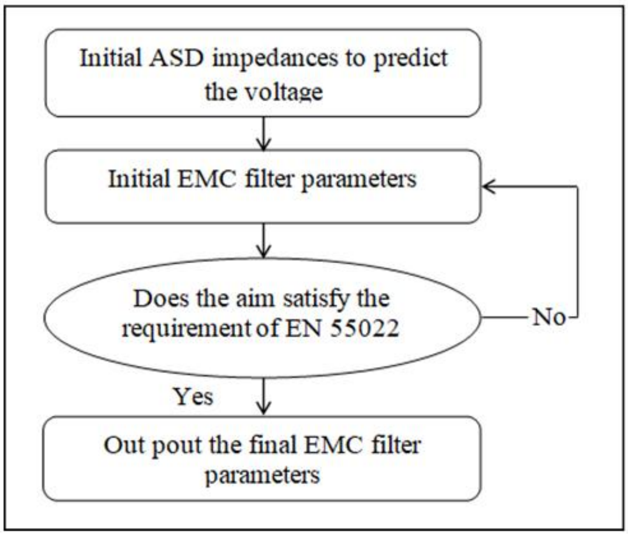

Figure 5. Diagram for the optimization procedures

Results and Discussion

This optimization approach consists of bringing the level of emissions of the voltage generated towards the network and which will be below the EMC standard, to the frequency range 150 kHz -30 MHz. Indeed, it is interesting to see the impact of the filter upstream and downstream of the inverter on the CM currents circulating throughout the system. The optimized EMC filter elements are: L_{CM}=2.8 mH, C_{CM}=0.8 pF.

Influence of the Filter on the Conducted Emissions Generated to the Network

The analysis begins with an observation of the common-mode voltage at the LISN, with and without an optimized filter to respect the standard EN 55022 –Class A- (Figure 6).

Spectrum of Common Mode Voltage in LISN

The common mode voltage in the LISN is well reduced, over the entire frequency range imposed by standard EN55022 (Figure 6).

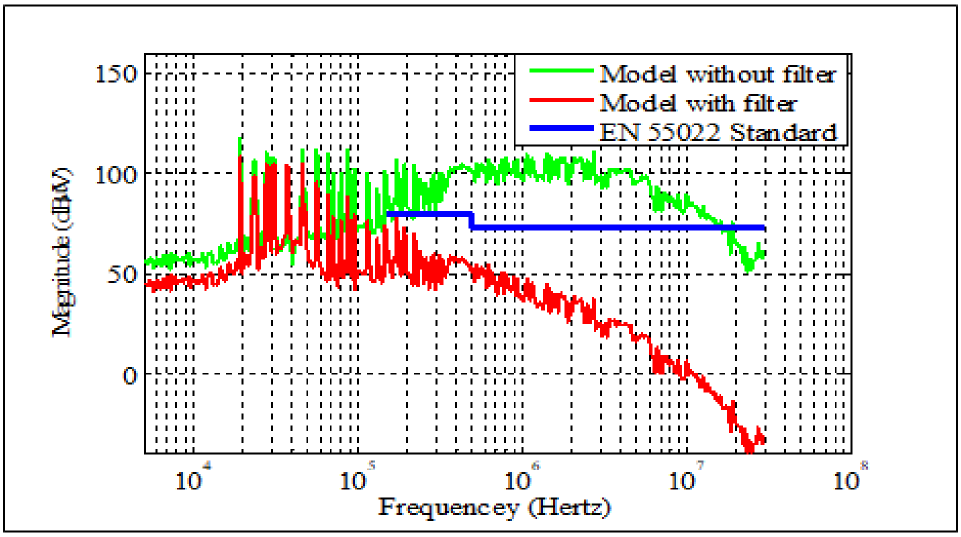

Figure 6. Spectrum of common mode noise in the ASD system (with and without input EMC filter)

Influence of the EMC Filter on the Conducted Emissions Generated to the Motor

To see the effectiveness of the presence of the filter at the input of the variable speed drive on the CM current at the input of the inverter. Figure 7 presents the corresponding current spectrum.

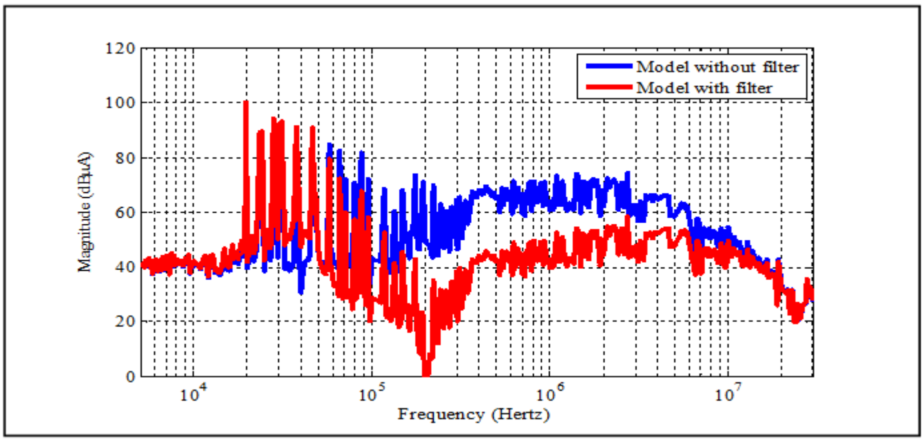

Figure 7. Spectrum of common-mode input currents in the inverter (with and without input EMC filter)

As we have seen previously, the input filter has a very limited effect on the common-mode current spectrum of the motor, despite a clear improvement from 150 kHz. The emission level remains almost identical to that calculated in the absence of the EMC filter for a large part of the frequency imposed by the corresponding standard (Figure 8).

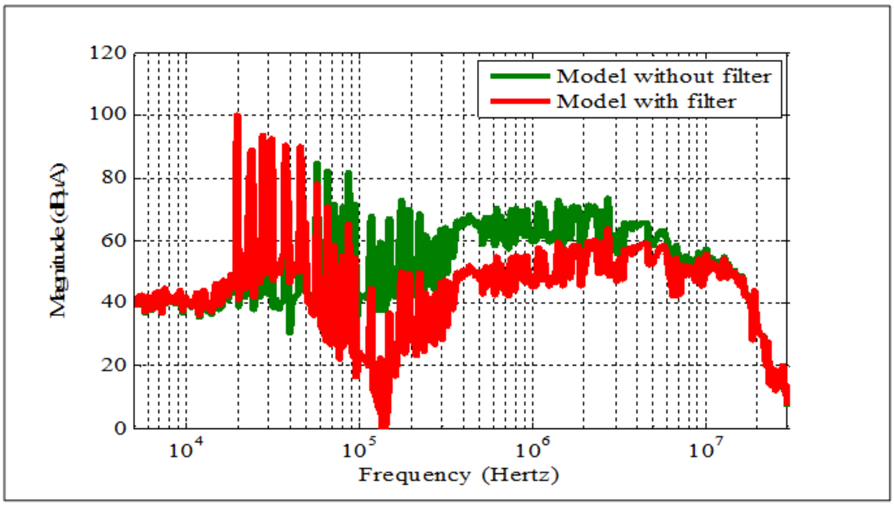

Figure 8. Spectrum of common-mode output currents in an ASD system. (with and without input EMC filter)

Conclusion

At this stage, we can conclude that the constraints are naturally respected, since the spectrum remains lower than the template, this type of filter is particularly effective for the normative aspect. But unfortunately, it has no action on motor overvoltage and does not reduce the common mode currents circulating in the motor.
Finally, it can be seen that this filter confines the disturbances circulating in the drive-cable-machine assembly as follows:

- The common mode choke constitutes a brake on the passage of the common mode current by increasing the impedance on the network side;
- Capacitors, connected to earth, offer low HF impedance and therefore form a privileged path for the return of the current, ensuring the confinement of disturbances.

The advantage of its LC structures at the entrance is that they are simple to implement, in terms of dimensioning and construction. The operating range of these filters goes from a few tens of kHz to tens of MHz. Beyond these values, the efficiency of HF inductors decreases and their inter-turn capacitances become preponderant, conferring a capacitive behavior on the inductor. In the same way, capacities become inductive from a certain frequency. These phenomena make it difficult to optimally size the filter, which can become ineffective above a certain frequency.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

Funding

* This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Technology, Engineering and Science (www.icontes.net) held in Antalya/Türkiye on November 12-15, 2025.

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To cite this article:

Miloudi, H., Miloudi, M., Bermaki, M. H., Mendaz, K., Gourbi, A., & Bendaoud, A. (2025). Electromagnetic interference (EMI) in variable-speed AC electric drives: Mechanisms and solutions. *The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 38*, 12-19.