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Optimization of EMC Filter for a Variable Speed Drive System in Electric Aircraft

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Abstract: In recent years, static converters are in constant evolution, and they have occupied an increasing role within aeronautical on-board networks. This development results in an increase in the power density of the onboard network and a reduction in the volume of the components. This development in electrical technologies creates problems related to electromagnetic pollution. To avoid polluting their environments, the power electronics designer will have to provide effective devices and means to mitigate the levels of emissions from their equipment. This work focuses on electromagnetic compatibility (EMC) problems appearing in power converters on board future more electric aircraft. The work deals with the aircraft EMC issue, and then the reduction of electromagnetic pollution from a variable speed drive system. With the standards used in the aeronautical fields, type DO 160D, the optimization approach consists in bringing the level of emissions of the current generated towards the network and the load Induction motor) below the EMC standard in the whole range of frequencies 150 kHz -30 MHz.

Keywords: Aircraft, Do-160d Standard, Electromagnetic compatibility, Optimization.

Introduction

Electromagnetic interference (EMI) is an inevitable occurrence in electrical and electronic systems. In adjustable-speed AC motor drive systems, a crucial component is the PWM inverter, widely utilized in industrial and aircraft applications. This inverter serves as a major source of conducted noise emissions, especially common mode (CM) noise, leading to significant noise current issues, particularly at high frequencies (HF). (Jettanasen, 2010). The EMI caused by switching power supplies interferes with the normal operation of other sensitive equipments and may cause operating faults (Miloudi et al., 2012). the Electromagnetic interference analysis within the system aircrafts is an important part of system design (Yanyan et al., 2020).

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). Certain EMI filter design approaches simplify the process by disregarding the noise source and termination impedances. Meanwhile, other methods

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consider these factors but simplify them as purely resistive elements (Miloudi et al., 2012). In this paper the crucial aspects of electromagnetic protection for aircraft electromechanical systems in intricate electromagnetic environments are examined in conducted electromagnetic interference.

EMI in Variable Speed Drive System

The subject of our study is a variable speed drive system. This type of drive is currently available in the market, utilizing IGBT power transistors with switching speeds 20 times faster, and its conventional topology is presented in Figure 1. It consists of an Input Rectifier bridge, a voltage inverter, all connected through a continuous capacitive bus, and the load comprised of a three phase induction motor and its power cable. The rapid switching in power converter represents a significant cause of Electromagnetic Interference (EMI) (Feloups et al., 2023), posing challenges in complying with EMC regulations. To adhere to these regulations, EMI filters are frequently incorporated into the converter front end (Ashritha et al., 2018). Variable speed drives are required to adhere to regulations concerning both conducted and radiated disturbances. These standards ensure that a system can operate effectively within its environment without generating electromagnetic disturbances that are disruptive to nearby equipment (Zeghoudi et al., 2022).

In this work, we will focus specifically on common mode currents, which refer to currents flowing between the power module and the ground. The simultaneous presence of parasitic capacitances and high voltage gradients across these capacitances causes the circulation of a current. Capacitive coupling is one of the methods through which electromagnetic disturbances are transmitted. Therefore, quantifying the parasitic capacitances of a power module provides an indication of the module's susceptibility to disturbances. The common mode current is caused by variations in the common mode voltage generated by the inverter, and it is responsible for radiated disturbances. It can be calculated based on the knowledge of the common mode voltage imposed by the inverter and the common mode impedances of the system.

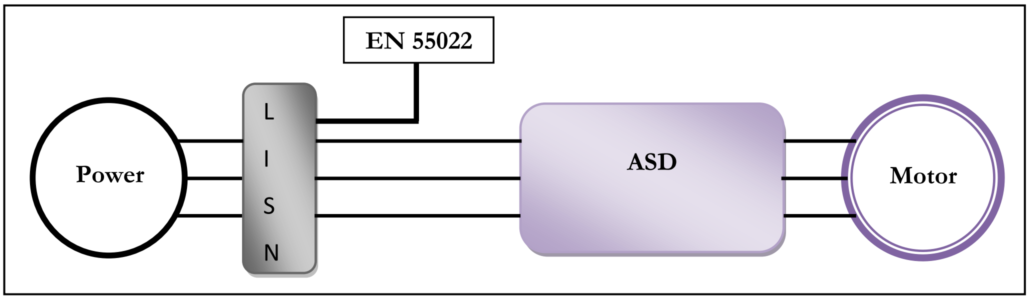

Figure 1. Adjustable speed drive structure

Common Mode Disturbances (CM): these emissions are generated by the flow of a capacitive current that propagates in all conductors in the same direction, and the return path is through the ground. This current is primarily due to the parasitic capacitances of the system excited by the dV/dt generated by power switches.

DO-160D Standard

RTCABO-160D, which stands for "Environmental Conditions and Test Procedures for Airborne Equipment," establishes a set of baseline environmental test conditions (categories) and the relevant testing procedures for airborne equipment (Borgstrom, 1998). This aeronautical standard aims to quantify electromagnetic noise at the input and output of the static converter in the radio frequency band (150 kHz – 30 MHz).

EMI Filter Configuration

In power conversion systems employing switches, the inherent rapid changes in voltage (dv/dt) and current (di/dt) during switching operations can generate substantial electromagnetic interference (EMI) noises. Conventionally, passive EMI filters are applied to mitigate these disruptive switching noises (Penugonda., 2021).

The configuration of a Common mode CM filter ideally comprises series inductors in each phase followed by parallel capacitors, as illustrated in Figure 2. The winding of these inductors is designed in opposite phases to neutralize the flux produced by CM current (Chaiyan et al., 2010) .

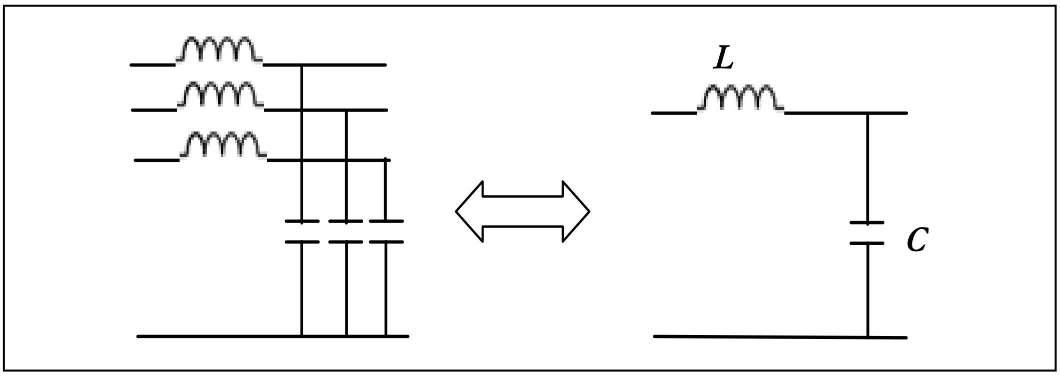

Figure 2. EMC filter (LC configuration)

The EMC filter in LC configuration can be given by the relation:

$$Z(p) = X_L * p + \frac{1}{X_C * p}$$

A passive filter solely relies on passive components to mitigate conducted disturbances, as noted by various researchers (Jon et al., 2021; Penugonda et al., 2021). These filters operate without the need for an external power supply. This approach enables strategic alteration of the disturbance propagation path, impeding their circulation, as demonstrated in studies by (Gregorio et al., 2017). for standard aspect the passive filters can be positioned upstream drive. An EMC filter designed to minimize the circulation of PEMs (Power Electronics Modules) generated by the converter outside of it will be positioned between the LISN and the converter input (Figure 3).

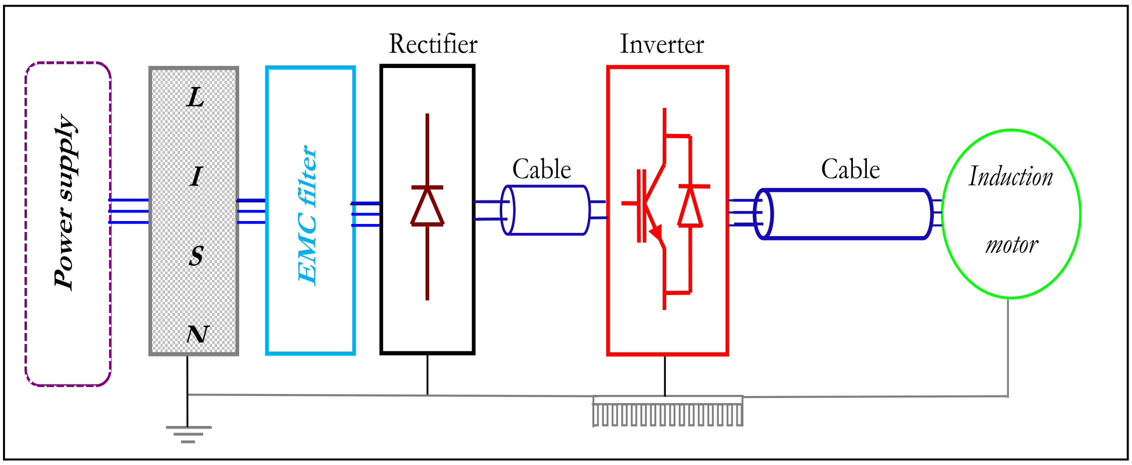

Figure 3. Input EMC filter on of ASD

The CM filter is placed upstream of the network, a technique commonly employed by modern variable speed drive systems. The combination of high impedance (inductance) and low impedance (capacitance) pathways effectively channels disruptive currents along routes that do not interfere with the network. When striving to optimize EMC performance, incorporating EMC constraints involves evaluating the level of emissions (spectrum envelope) at the input of the variable speed drive in relation to the limit specified by the DO-160D standard for the corresponding frequency.

In this study, the optimization approach consists of reducing the emission levels exceeding the limit of EMC standard to below it over the entire corresponding frequency range.
The optimization flowchart is shown in Figure 4.

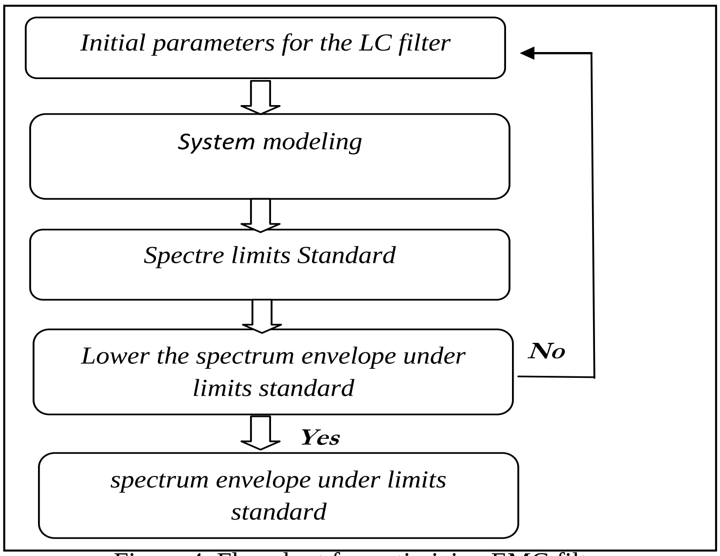

Figure 4. Flowchart for optimizing EMC filters

Results and Discussion

This optimization method aims to lower the emissions generated by the current flowing into the network, ensuring they stay within the EMC standard, specifically in the frequency range of 150 kHz to 30 MHz. Examining the influence of the filter placed before the inverter on the common mode currents circulating throughout the system is crucial. The optimized values for the EMC filter elements are determined through this analysis: L_{CM}=2.8 mH, C_{CM}=0.8 pF.

EMC Filter Performance

In the first, the spectral estimates are referenced to DO-160D standard, the aerospace standard used for evaluating conducted disturbances in the analyzed system, and they measure electromagnetic noise at both the input and output of the variable frequency drive.

Spectrum of Common Mode Currents in the Input of the ASD System

The common mode current in the input of the variable speed drive system is well reduced, over the entire frequency range imposed by standard DO-160D (Figure 6).

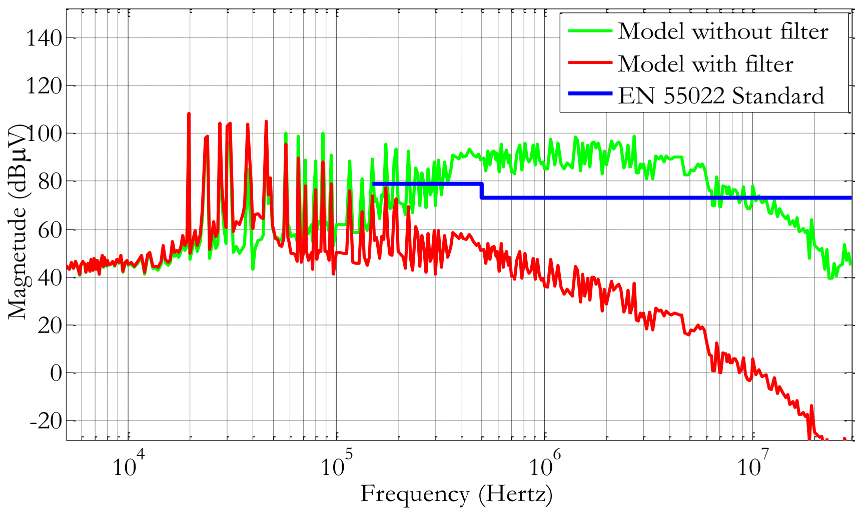

Figure 5. Currents in the input of the ASD system

To see the effectiveness of the presence of the EMC filter at the input of inverter, we show in figure 6 the spectrum of the current.

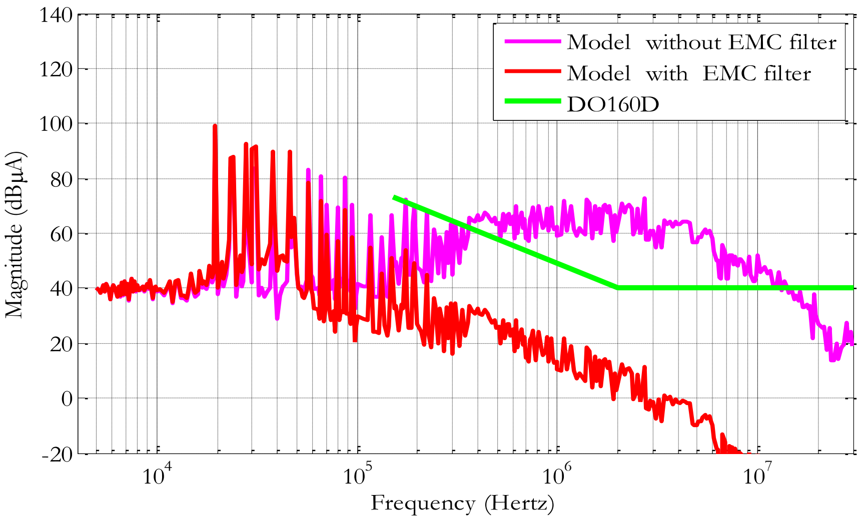

Figure 6. Currents in the input of inverter (with/ without EMC filter)

An input filter is a circuit component used to suppress electromagnetic interference (EMI) or radio frequency interference (RFI) in ASD system. It's often employed to meet electromagnetic compatibility (EMC) standards, which specify the acceptable levels of electromagnetic emissions from electronic devices.

The common mode current can cause electromagnetic interference and needs to be controlled to comply with EMC standards. The proposed filter suggests that the input filter has a positive effect on reducing interference at this specific frequency. From figures 5 and 6, the system still meets the EMC standard requirements. The emission levels remain within the acceptable limits set by the standards,

EMC Filter Effect on the Common Mode Current Generated to the Motor

The figure 7 presents the CM current generated to the motor, in order to see the effect of an EMC filter.

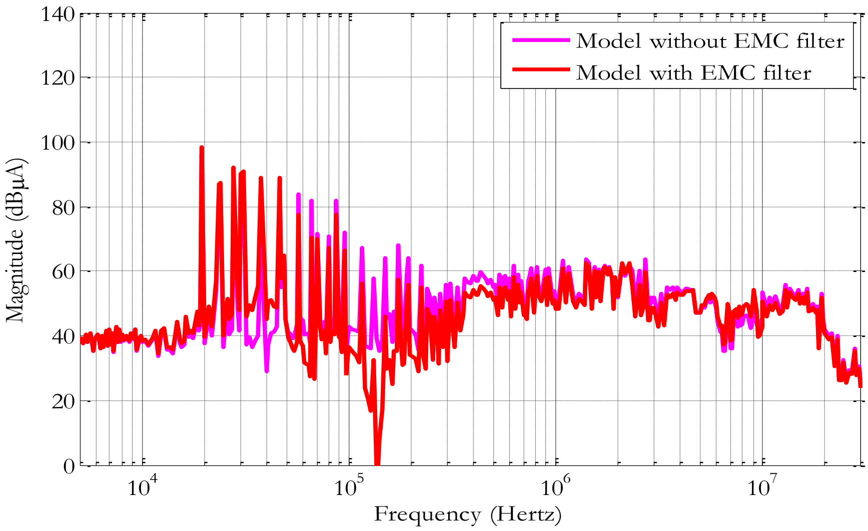

Figure 7. Currents in the motor

As we have seen previously, the results assert that despite the presence of the input filter, there is no significant change in the spectrum of common mode current in the motor. This means that the filter doesn't affect the distribution of interference across different frequencies (Figure 7).

Conclusion

Improving electromagnetic compatibility acts on the side of the sources by trying to reduce the disturbances they emit. The filter presented with an inductance alone is sufficient to limit disturbances and keep the spectra below the corresponding limits. Therefore, the inductance significantly attenuates conducted electromagnetic disturbances (PEMs), and the capacitance of the filter remains secondary to the inductance in reducing conducted emissions, the common mode choke acts as a barrier, hindering the flow of common mode current by elevating the impedance on the network side. Meanwhile, capacitors, grounded and providing low high-frequency impedance, create a preferred pathway for current return. This arrangement ensures the containment of disturbances.

In the frequency range considered, the proposed EMC filter is particularly effective for the normative aspect, and gives best EMC performance. 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.

Scientific Ethics Declaration

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

Acknowledgements or Notes

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