Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 9, S. 45-53, 2, 2025
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Araştırma Makalesi

IJANSER
https://as-proceeding.com/index.php/ijanser
ISSN:2980-0811

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 9, pp. 45-53, 2, 2025
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Research Article

Analysis of Common-Mode and Differential-Mode Noise in DC Motors with Variable Speed Drives

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(Received: 31 January 2025, Accepted: 03 February 2025)

(2nd International Conference on Pioneer and Innovative Studies ICPIS 2025, January 30-31, 2025)

ATIF/REFERENCE: Lahlaci, M. E. A, Miloudi, M., Miloudi, H., Abdelber, B., Bermaki, M. H., Gourbi, A., & Hakmi, Y. (2025). Analysis of Common-Mode and Differential-Mode Noise in DC Motors with Variable Speed Drives. *International Journal of Advanced Natural Sciences and Engineering Researches*, 9(2), 45-53.

Abstract –Electric drives based on direct current motors are very numerous in several application areas such as traction, hoisting, submarine propulsion and machine tools. Variable speed drives must comply with the standards for conducted and radiated disturbances. These standards guarantee the ability of a system to function satisfactorily in its environment without producing intolerable electromagnetic (EM) disturbances for neighboring equipment. In this paper, we present the study of the conducted electromagnetic interference (EMI) of a variable speed drive of a DC motor. The variable speed drive is a DC/DC serial chopper, and the variation is done by the switching frequency of the MOSFET. The conducted disturbances in common mode (CM) and in differential mode (DM) generated are presented.

Keywords –DC Motor, Series Chopper, Common Mode, Differential Mode, Variable Speed Drives.

I. INTRODUCTION

Electromagnetic Interference (EMI) has become a major challenge in modern electrical engineering, particularly with the growing use of Adjustable Speed Drives (ASDs) and electric motors across a wide range of industrial applications [1]–[8]. As these technologies evolve and their implementation becomes more widespread, mitigating EMI is crucial for ensuring the reliable operation of electrical systems and meeting stringent electromagnetic compatibility (EMC) standards.

This paper specifically addresses the significant issue of EMI in motor systems, with a focus on Common-Mode (CM) noise. CM currents and voltages can severely disrupt system performance, degrade efficiency, and compromise the surrounding electromagnetic environment. As international EMC regulations tighten, understanding the underlying causes of CM interference is essential not only for regulatory compliance but also for maintaining the reliability, stability, and safety of electrical systems. A comprehensive analysis of CM interference is the first step in formulating effective strategies to reduce EMI, which are vital for ensuring the long-term functionality and integrity of industrial electrical infrastructures.

Efficient EMI management in motor systems is not only necessary for adhering to regulatory standards but also for optimizing the performance and stability of electrical networks. Recent research has highlighted the importance of controlling EMI in energy-efficient and high-performance systems. For instance, Swami [25] emphasizes the need for specialized design standards in low-power embedded systems to achieve energy savings while maintaining strong electromagnetic performance. Likewise, studies such as [26] explore the impact of multilayer driver configurations on EMI in high-voltage settings, while [27,28] stress the role of EMI control in maintaining the reliability of advanced smart manufacturing systems.

The electric machine was the first to be put into service and has long been the main solution for achieving electromechanical conversion because of its simplicity of operation. A DC machine (DCM) is an energy converter. It converts mechanical energy into electrical energy and vice versa. In the first case, the machine is a generator; in the second case, it is a motor [29]. These machines are power actuators, widely used in many industrial applications, robotic manipulators and commercial applications such as servo and traction tasks, disk drives, etc. due to their efficiency, robustness and relative tradition [30]. The considerable development of semiconductors (transistors, thyristors...), has led to considerable progress in industrial electronics, essentially consisting of power electronics and control electronics (and possibly regulation). Industry, in the broadest sense of the term, and transport in particular, increasingly requires systems that can be continuously varied in speed with flexibility and precision in several application areas [31]. DC motors are widely used in automatic systems that require precise speed control. The principle of speed control is to control the speed of the motor and to choose the right converter. Voltage converters (static, converters). Currently, these speed controllers (series chopper) are devices with electronic switches (semiconductor components such as diodes and MOSFETs).

However, static converters are sources of significant electromagnetic interference (conducted and radiated), due to their very short switching times at very high amplitudes. These fast-switching operations reduce switching losses due to the simultaneous presence of voltage and current in the switches [32]. Another factor that increases electromagnetic pollution is the very high switching frequency, which can cause electrical or electronic systems to malfunction. In electrical power conversion systems, the chain usually includes all the conversion steps between the AC/DC power source and the load. These steps often include an AC/DC rectifier followed by a switching stage, such as variable speed drives of associated machines, an inductively switched power supply, etc., takes into account the power lines, filtering, grid impedance stabilization system (LISN) [33-35], as shown in figure 1.

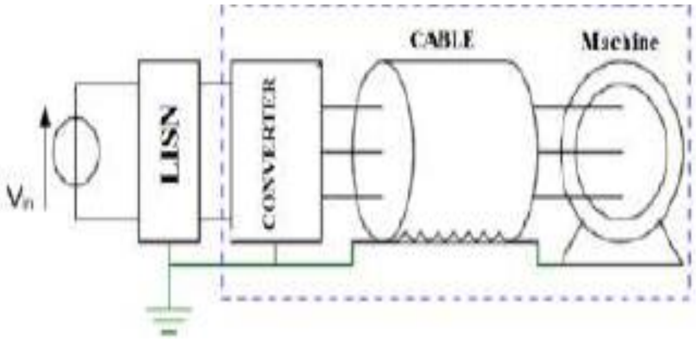

Fig. 1 Variable speed drive for a machine

The objective of this work is mainly to determine the emissions conducted in common mode and in differential mode for the variable speed drive of the DC motor using simulation on the LTspice software.

II. DIRECT CURRENT MOTOR

The DC motor is an electromechanical energy converter. It transforms continuous electrical energy into mechanical energy to drive a moving load. It consists of a fixed part, the stator (inductor), and a moving part, the rotor (armature) (Fig.2) [36].

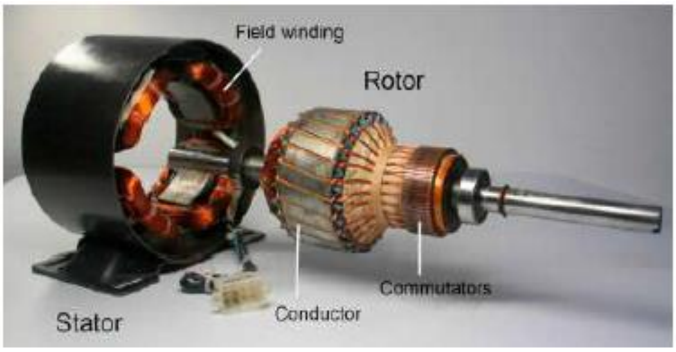

Fig. 2 Energy conversion in a DC motor.

III. EMC OF STATIC CONVERTERS

The disturbances conducted and radiated by a static converter have a common origin, determined by its electrical operation and material layout. To the initial electrical structure, localized parasitic components are added. This makes it possible to determine the converter waveforms and the different conducted currents by taking into account the geometrical aspects.

A. Origin of disturbances in a converter:

. The electrical diagram of the converter is not sufficient to explain the waveforms observed, let alone the resulting electromagnetic disturbances. Indeed, the wiring and the topology will introduce parasitic elements and couplings. It is therefore necessary to introduce two types of parasitic components in the converter.

- Parasitic components of the circuit type: targeting inductances, semiconductor capacitances, inductive or capacitive imperfections of passive components. They modify the theoretical waveforms of the converter and create the often-oscillatory high-frequency oscillatory regimes at high frequencies. They are superimposed on the theoretical waveforms and they are superimposed on the theoretical waveforms and intervene directly on the current absorbed in differential mode.
- Parasitic coupling components: in the structures studied, they are essentially made up of the coupling parasitic components: in the studied structures, they are essentially constituted by the package-radiator capacities of the semiconductors or of targeting concerning the chassis. These elements are distributed, but their role is predominant for these elements are distributed, but their role is predominant to the high dV/dt equipotentials in the structure.

B. Electrical mechanisms for generating disturbances:

The electromagnetic disturbances occurring during switching are the result of two effects:

- The conductors subjected to dV/dt and dI/dt become sources of currents, voltages and stray fields;
- The operation (switching) of the converter determines the dynamic regimes of dV/dt and dI/dt, and thus all excitations of the parasitic circuits.

IV. SOURCE OF EM DISTURBANCES

The chopper is used to control the armature voltage of a DC motor. The DC motor circuit powered by a chopper is shown in figure 3. The chopper switch is a power MOSFET with very fast frequencies around one hundred MHz and very short switching times of around one hundred ns. As well as a low RDS resistance (resistance between drain and source), which reduces conduction losses but produces extremely high voltages and currents and the variation of electrical quantities as a function of time and of the passive components causes very significant electromagnetic interference [37,38].

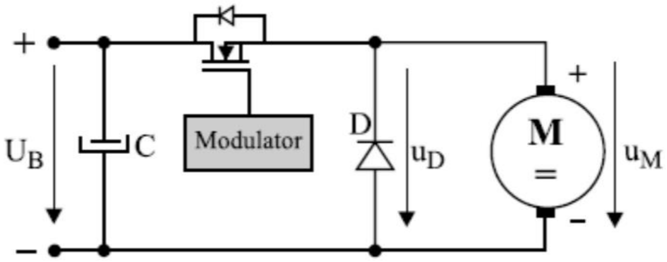

Fig. 3 Variable speed drive of a DC motor

The most frequent modes of propagation of electromagnetic disturbances are the differential mode (DM) and the common mode (CM) as shown in figure 3. There is the common mode when the current circulates in all conductors in the same direction until the victim and the return is made by a ground plane. The second mode is the differential mode when current flows through one conductor to the victim and back through another conductor in the opposite direction [39].

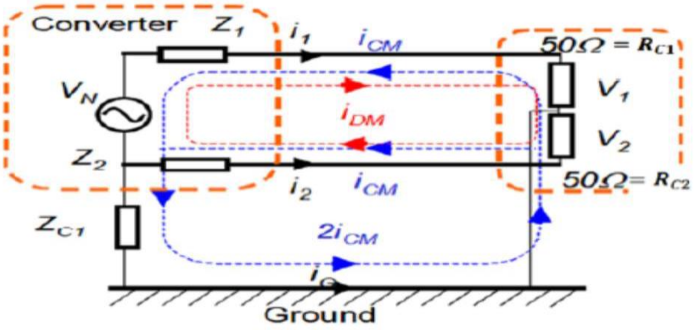

Fig. 4. Pollutions in differential and common modes

The differential mode current I_{DM} flows in the loop between two power lines and the common mode current I_{CM} flows in the overall loop, including the power lines and the ground [16,17]. Thus, the real interference current in two power lines is:

$$I_1 = -I_{CM} + I_{DM} \qquad (1)$$

$$I_1 = -(I_{CM} + I_{DM}) \qquad (2)$$

The relations (3) and (4) express the both voltages V_1 andV_2, at the terminals of the resistors R_{C1} and R_{C2} respectively:

$$V_1 = R_C\, I_1 \qquad (3)$$

$$V_1 = R_C\, I_2 \qquad (4)$$

With: $R_C = R_{C1} = R_{C2} = 50\ \Omega$.

The relations (5) and (6) express the common and differential modes voltage respectively from the voltages of each of the supply phases.

$$V_{MC} = \frac{V_1+V_2}{2} = -50 I_{CM} \qquad (5)$$

$$V_{MC} = \frac{V_1-V_2}{2} = 50 I_{DM} \qquad (6)$$

V. AC/DC CONVERTER ASSOCIATED WITH DC MOTOR

To examine the EMC disturbances caused by the electrical system, we simulated a variable speed drive (series chopper) feeding a DC motor in two modes: common mode and differential mode, as shown in figure 5. The main elements of the LTspice software circuit: are the Line Impedance Stabilization Network "LISN", an AC source, an AC/DC converter (a diode bridge) that feeds the chopper and another square-wave source to control the IRF740 type MOSFET and, a MUR460 type diode, the parasitic elements and the DC motor equivalent. The MOSFET is controlled with a duty cycle of 50% and a switching time of

105µs. The "LISN" device is connected to the start of the static converters to measure the conducted emissions generated by this model. The voltage of the AC source is equal to 200 V, 50 Hz AC.

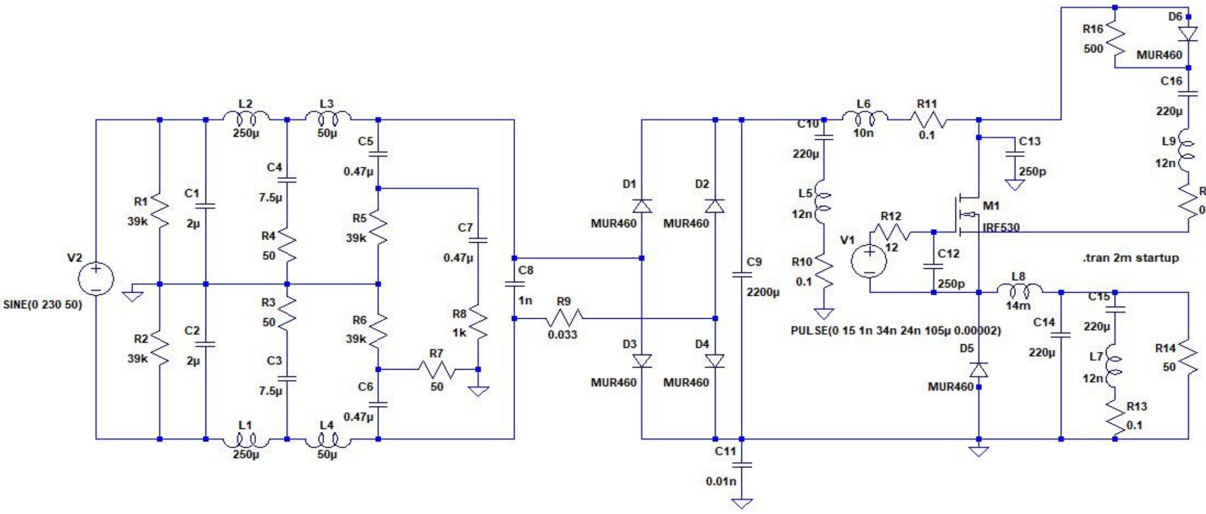

Fig. 5 Variable speed drive DC model

VI. RESULTS

Figure 6 shows the rectified voltage that feeds the speed controller for an amplitude of 200 V between 5ms and 100ms.

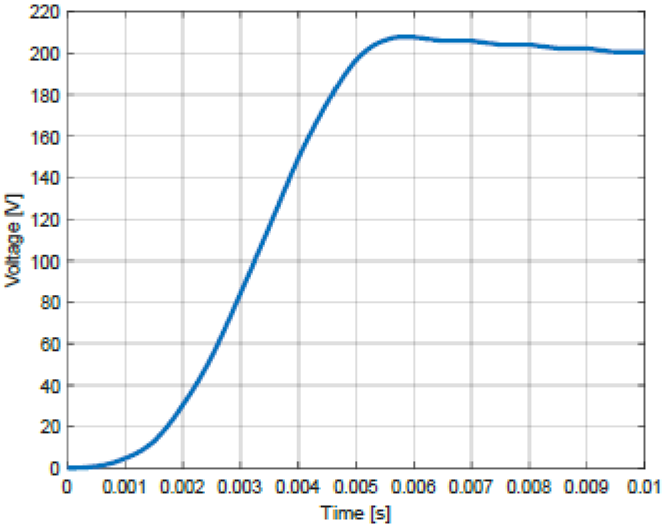

Fig. 6 Rectifier voltage

Figure 7 shows a control signal of the chopper (MOSFET type IRF530). The voltage has a square wave signal of 15 V with a duty cycle of 0.5 with a frequency of 5 kHz or the period T = 20 µs.

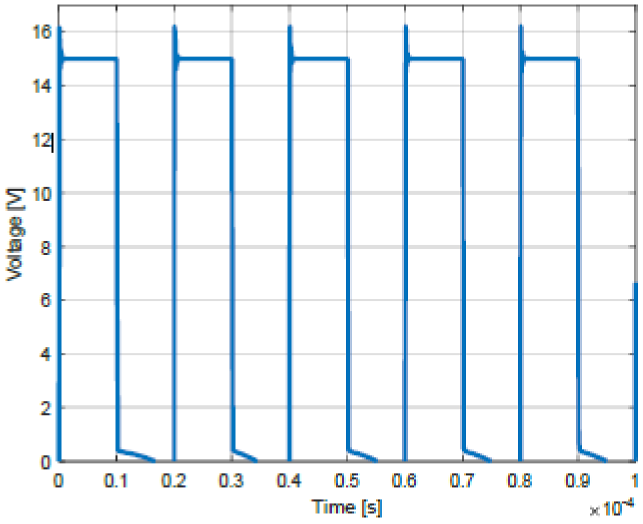

Fig. 7 Control signal at the chopper level

Figure 8 represents the variation of the current at the motor level which is in the form of a pulse or it controls the variation of the speed for our model.

To test EMI performance in both CM and DM, the EN 55022 (Fig. 9) and DO160D (Fig. 10) Standards Line Impedance Stabilization Network (LISN) are utilized. Fig. 9 displays two separate propagation routes for DM and CM sounds in this investigation. When comparing DM and CM emissions, it is evident that the CM has a significant advantage. The switching node parasite capacitance is the key component responsible for CM currents. The most prevalent power component in power electronics is the MOSFET, and it is the cause of the interruptions. It is commonly employed in high-frequency operations [7]. With low voltage and low gate drives, the parallel current is easy, and the bipolar junction is devoid of side effects. The parasitic components of the diode crossing are unimportant since they do not affect it. Because the converter is not needed to meet cost or thermal limits, the MOSFET selected has been overestimated to ensure a range of test conditions without altering the MOSFET.

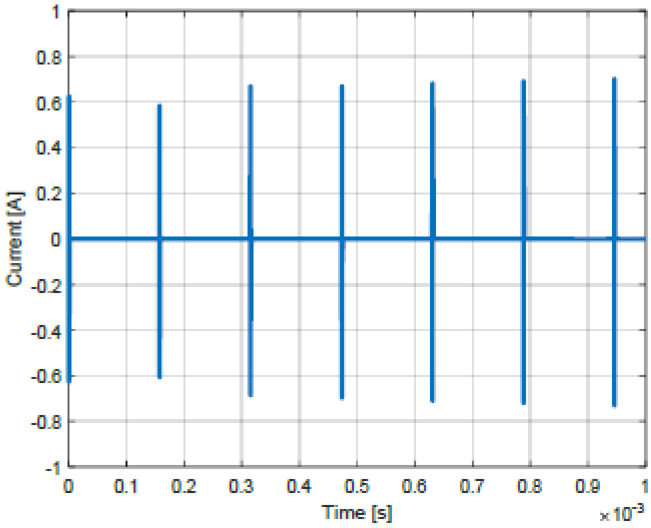

Fig. 8 The motor current signal

On the other hand, the common and differential mode currents for an amplitude do not exceed the DO160D standard, despite the minimization of the interface in high frequency (Fig. 10).

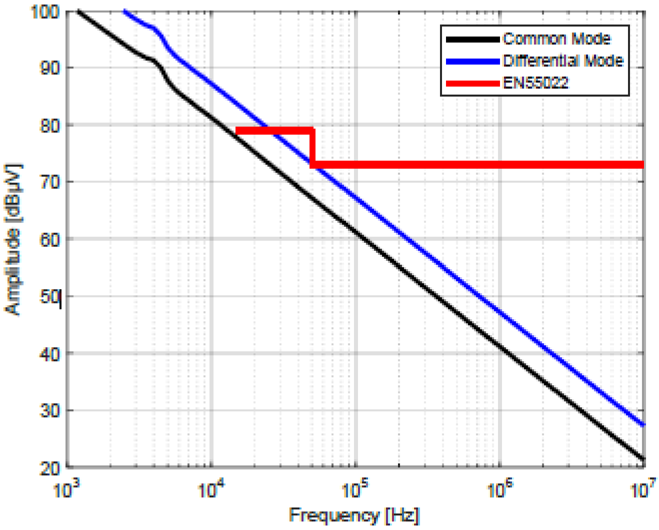

Fig. 9 Voltage common mode and differential mode

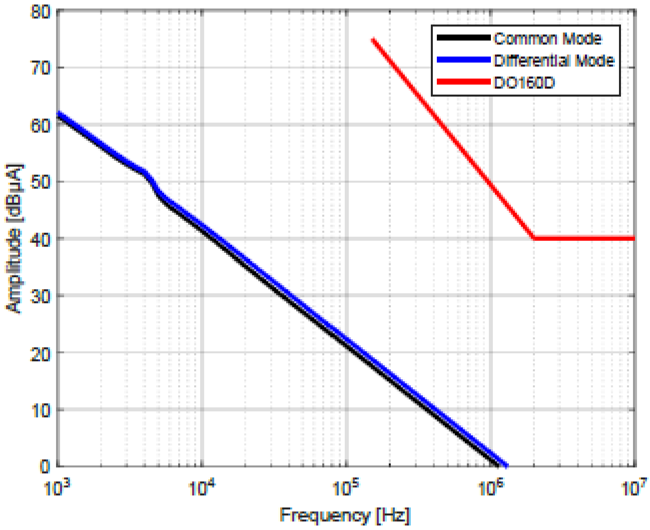

Fig. 10 Current common mode and differential mode

VI.CONCLUSION

Electromagnetic interactions (EMI) are the common thread of this work, and this discipline has one of the largest fields of application. In the no less complex case of power electronics, electrical systems are more and more used in our days, and widely used in the domestic, industrial, military, communications, or transportation, they can cause on its environmental disturbances of electromagnetic nature, which makes electromagnetic compatibility essential for the safety of goods and people.

In this article, we studied a model of a cruise control of a direct current motor (serial chopper), our study is based on a simulation on the LTspace software to characterize the perturbations conducted in the time and frequency domains.

As the results of this article are considered, the switching speed of the components (dv/dt), the current variations (di/dt), as well as the parasitic elements, are the key factors that decide the EMI performance in a switching cell.

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