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ELECTROMAGNETIC INTERFERENCE AND POWER QUALITY BEHAVIOR OF SELECTED COMMERCIAL LED DRIVERS

ABDELHAKIM ZEGHOUDI[1*], DORIN LUCACHE[2], DRAGOS ASTANEI[2*], BENDAOUD ABDELBER[1], LAURENT CANALE[3]

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Over the last decade, the domestic lighting market in Romania has been significantly transformed by the adoption of LED technology. Despite compliance with EU standards, LED product quality still varies, making it essential to evaluate their performance and impact on the power grid. This paper presents a detailed analysis of power quality (voltage and current harmonics) and electromagnetic interference in both common-mode and differential-mode, using time- and frequency-domain measurements of two commercially available LED drivers. The results indicate that, while LEDs offer substantial energy savings, some products generate notable harmonics and EMI, in certain cases exceeding recommended limits, highlighting the importance of careful product selection and characterization for reliable grid integration.

1. INTRODUCTION

The European Union attaches great importance to energy efficiency as part of its European strategy. This strategy includes three major and complementary objectives by 2020: reduce greenhouse gas emissions by 20% compared to 1990, increase the share of renewable energies in primary energy production to 20%, and improve the efficiency of energy by 20% [1–3]. This involves an international roadmap to bring LED lighting to 100% of the lighting market before 2023 (today, LED covers 70% of the lighting market, with nearly $50 billion in turnover) [4–7].

At COP28 (Dubai, December 12, 2023), the European Union announced commitments to accelerate the energy transition, including tripling renewable energy capacity and doubling the pace of energy-efficiency improvements by 2030, supported by a €2.3 billion EU budget investment across Europe. Improving the energy efficiency of public lighting is therefore essential. It can significantly reduce electricity consumption, phase out environmentally harmful technologies, lower maintenance costs, and enable more efficient overall lighting management [1].

Romania's lighting market has strong growth potential and, as an EU member, benefits from legislation and funding (Environmental Fund Agency, National Recovery and Resilience Plan) to modernize public lighting. However, by 2022, only about 25% of ~2 million street and road lamps had been converted to LED. Further upgrades are expected in schools, hospitals, and other public buildings, contributing to electricity use of about 500 million kWh in 2022—around 15% below the previous two-year average [8]. A study conducted by Signify Romania has demonstrated that a complete transition to LED lighting in public lighting sectors could reduce the country's energy costs by up to 150 million euros annually [9].

This article presents a study of two commercially selected LED drivers in Romania: brand a) Tridonic 50 W and brand b) TCI (Telecommunications Company Italy) > 46 W. Both brands power two TCI LED modules, each with a power of 25 W, the two modules connected in parallel. The study aims to evaluate the impact of LED lighting systems on the energy quality of the electrical network, current and voltage waveforms, and harmonics, in accordance with EN IEC 61000, -3-2 class C (low frequency); then measuring and analyzing EMI (common mode, differential mode) and comparing the results with the EMC standard EN55015 (Quasi-peak).

2. ELECTROMAGNETIC INTERFERENCE IN LED DEVICES

An LED consists of positively and negatively doped semiconductor crystals in a package that provides electrical contacts, light output, and heat dissipation. Its crystalline structure makes it durable and robust. When current flows, electrons transition between energy bands and emit radiation whose energy depends on the bandgap [10, 11].

LED lamps are highly efficient, converting up to ~30% of electrical energy into light (vs. ~2–5% for incandescent lamps). They are also durable thanks to their semiconductor structure: today's quality consumer LEDs reach about 160–170 lm/W and can last around 50,000 hours [11–14]. Additionally, LED lights require less maintenance, which helps reduce costs. They also provide increased security [15]. However, LED lamps can create harmonics and electromagnetic interference due to high-frequency switching in their power electronics. If filtering is insufficient, this noise can degrade power quality and cause conducted or radiated disturbances in nearby sensitive circuits [16-19]. If EMC measures are inadequate, LED-lamp interference can disrupt other equipment. Because lighting is widely used and consumes significant electricity, it is subject to dedicated standards, notably EN IEC 61000-3-2 Class C (low frequency) and EN 55015:2019-11 (high frequency) [20–22].

Table 1

The EMC Standard for regulating the harmonic current of lighting fixtures falls under IEC 61000-3-2, specifically Class C [23].

Harmonic component	Maximum permissible harmonic current expressed as a percentage of the input at the fundamental frequency
3	2
5	30*(power factor)
7	10
9	7
11	5
13 <n <39	3

The International Electrotechnical Commission (IEC) has established a series of guidelines for controlling low-frequency harmonics generated by grid-connected electronic equipment. Table 1 provides details of IEC 61000-3-2, which specifies harmonic emissions limits for lighting equipment with a power rating greater than 25 W, classified as Class C [23].

[1]APELEC Laboratory, Electrical Engineering Department, Djilali Liabes University, Sidi Bel-Abbes, BP 22000, Algeria.
[2]Electrical Engineering Department, "Gheorge Asachi" Technical University, Iasi, Romania.
[3]CNRS, LAPLACE Laboratory, UMR 5213, Toulouse, France.
E-mails: abdelhakim.zeghoudi@univ-sba.dz, dorin.lucache@tuiasi.ro, dragos.astanei@tuiasi.ro, abdelber.bendaoud@univ-sba.dz, laurent.canale@laplace.univ-tlse.fr

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The EMC standard EN 55015:2019 defines guidelines for luminaires, including LED lamps: This standard specifies the frequency ranges for conducted emissions, from 9 kHz to 30 MHz, and the quasi-peak (QP) limits) which are detailed in Table 2 [24].

Table 2

Disturbance voltage limits according to EN55015(quasi-peak) [26].

Frequency range	Limits (dBuV)		Method
	Quasi-Peak	Average	
9 kHz to 50 kHz	110	-	EN55016-6-2 and 8.3
50 kHz t– 150 kHz	90 to 80[b]	-	
150 kHz to 0.5 MHz	66 to 56[b]	56 to 46[b]	
0.5 MHz to 5 MHz	56[c]	46[c]	
5 MHz to 30 MHz	60	50	

[a] At the transition frequency, the lower limit applies

[b] The limit decreases linearly with logarithm of the frequency in the range 50 kHz to 150 kHz and 150 kHz to 0.5 MHz

[c] For lighting equipment incorporating exclusively electrodeless lamps, the limit in the frequency range of 2.2 MHz to 3 MHz is 73 dBuV Quasi-peak and 63 dBuV average.

3. **LED DRIVERS STUDIED**

The LED lamp is powered by the 230 V/50 Hz electrical network through the driver. Two types of drivers were used in the experimental measurements of harmonics and conducted electromagnetic disturbances, as illustrated in Fig. 1 and 2. A different manufacturer makes each driver. The two drivers are the most famous in Romania: brand a) TRIDONIC 50 W, brand b) TCI > 46 W. Table 3 shows the characteristics of the two electrical drivers in our work.

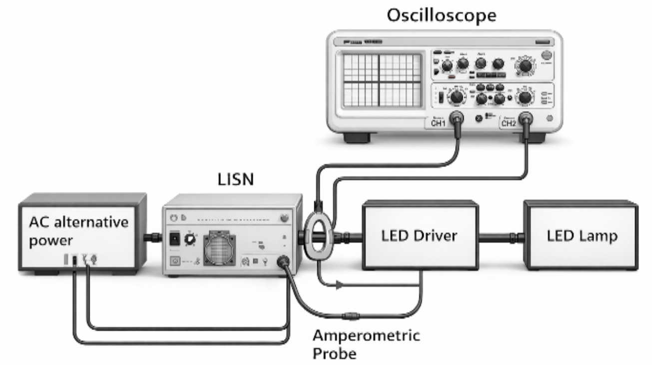


Fig. 1 – Setup diagram for conducted EMI measurements on LED drivers.

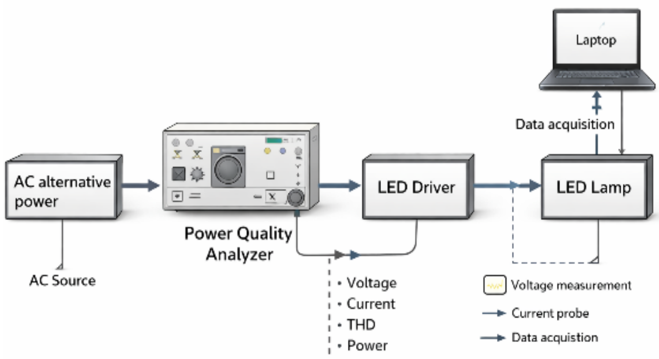


Fig. 2 – experimental setup for power quality analysis of a LED driver system.

The LED lamp consists of two TCI-type modules with a power of P = 25 W and maximum current I_{max} = 350 mA, with a calculated luminous flux equal to 140 lm/W, at the temperature of 65°C. The two modules are connected in parallel; each module consists of a series of LED semiconductors.

Table 3

Electrical characteristics of both brands of LED drivers.

Brand Type	Brand a)	Brand b)
Brand name	TRIDONIK	TCI
Power	50 W	>46W
Input Voltage	220/240 V	220/240 V
Frequency	50-60 Hz	50-60 Hz
Output Voltage	220-240 V	160-210 V
Input current	1000 mA-400 mA	350 mA-500 mA
Manufacture in	Austria	Italy

Electroluminescent light sources can generate harmonic currents well above the standard permitted limits. To check the quality of the LED drivers selected on the Romanian market, we therefore measured the electromagnetic interference conducted by the AC/DC LED drivers.

We tested power quality and EMC on specific light sources using a dedicated bench (Figs. 3–4). Measurements were performed on new lamps at 20–27°C after current stabilization, using a power-quality meter (harmonics), an oscilloscope (line current/voltage), and a current probe to assess differential- and common-mode disturbances.

The instruments used for these measurements provide complementary information on power quality and signal behavior. The Fluke Power Quality meters were employed to quantify voltage and current anomalies, such as harmonics, sags, swells, and phase imbalances. A spectrum analyzer allowed detailed frequency-domain analysis, identifying specific harmonic components and potential interference. The oscilloscope provided time-domain visualization of voltage and current waveforms, enabling the detection of transients, waveform distortions, and rapid fluctuations. Together, these tools ensured a comprehensive assessment of the electrical and electromagnetic characteristics of the LED drivers under test.

Fig. 3 – Test stand for measuring harmonic distortion generated by an AC/DC LED driver.

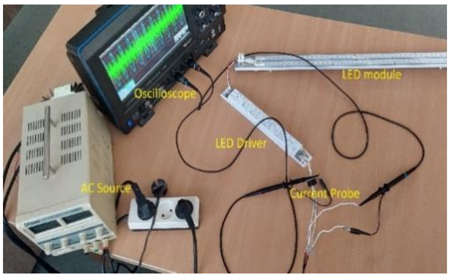


Fig. 4 – Test stand for measuring the conducted disturbance emission generated by the LED lamp under test in the frequency range 9 kHz-30 MHz.

4. **RESULTS AND DISCUSSION**

4.1 TOTAL HARMONIC DISTORTION (THD)

Beyond the number of LED light sources used as a load, the presence of harmonic components in the electrical network's current and voltage depends on the number of electronic devices used and the quality of the power supply. Figure 5 shows the voltage form applied to the terminal by the two drivers selected in this work, where the sinusoidal voltage signal form that depends on the Romanian power grid is the most common.

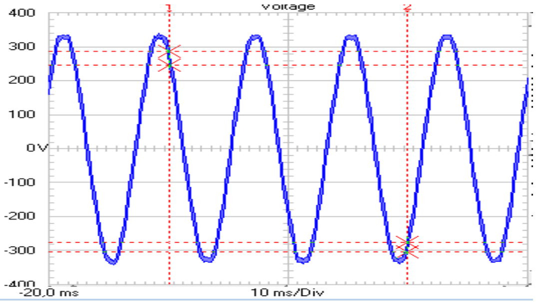
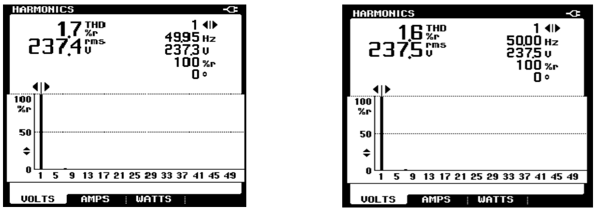


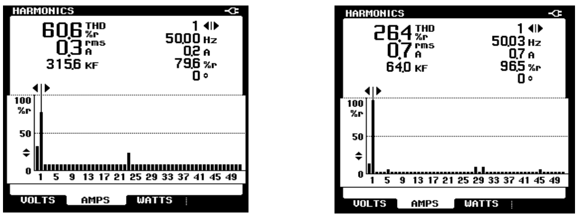
Fig. 5 – Form of the mains voltage signal applied to the terminals by the LED driver.

Figures 6 and 7 show respectively the voltage harmonics and the line current for the two brands, brand a) TRIDONIC, brand b) TCI powering two LED modules with power P = 50 W. we notice in the frequency band [50 Hz-2.5 kHz] that the voltage THD is negligible presenting 1.7%, for current harmonics, we note that brand a) has a greater THD than brand b), as well as the presence of harmonics in both brands are due to the non-linear loads of AC/DC electrical energy conversion by diodes. Despite this, the current THD remains compliant with IEC61000-3-2 standards.



Brand a) Brand b)

Fig. 6 – Voltage harmonics obtained from the power grid.



Brand a) Brand b)

Fig. 7 – Line current harmonics.

4.2 ELECTRICAL QUANTITIES AT THE DRIVER INPUT

Figure 8 shows the input current for both drivers, where brand b) is sinusoidal but with very fast peaks, which can be explained by the use of power factor correction by electronic power switches, with very high frequencies, while for brand a), the current signal is periodic but not sinusoidal, with very low peak variation.

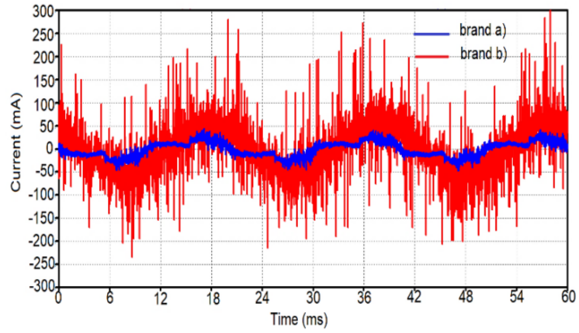


Fig. 8 – Temporal response of line current.

Figure 9 shows the line currents in the frequency domain, where the low-frequency harmonics are constant concerning brand a), while in the high-frequency domain, the electromagnetic disturbances in brand b) are greater than in the mark a), due to the rapid variation of voltage and current as a function of time by electronic switches.

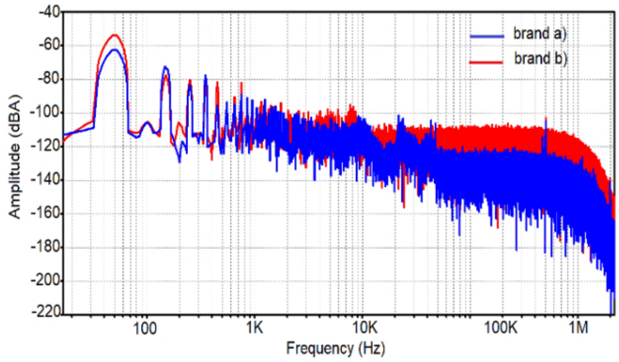


Fig. 9 – Frequency response line current.

4.3 ELECTRICAL QUANTITIES AT DRIVER OUTPUT

Figures 10 and 11 show the current at the driver output in the time and frequency domains, while Fig. 10 brand b) shows a stable signal shape due to the use of power factor correction, while brand a) shows a ripple. Figure 12 shows the driver output voltages for both marks, showing ripple at mark a) in the case of zooming in over one period. From these results, we can say that brand b) TCI gives lower THD and more stable electrical quantities at the driver output than TRIDONIC. Figure 12 shows the frequency spectra of the driver output voltage. We observe a peak at 35 kHz. Mark a) shows a larger peak than Mark b), with a minimization of the voltage spectra towards high frequencies.

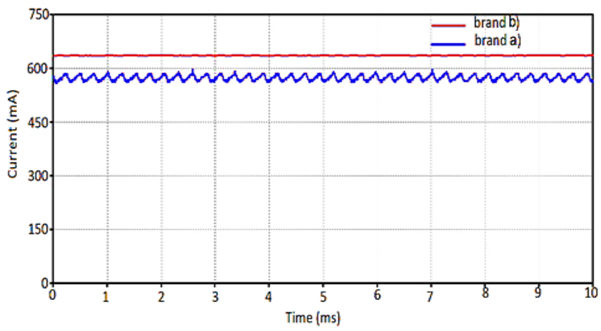


Fig. 10 – Current at driver output.

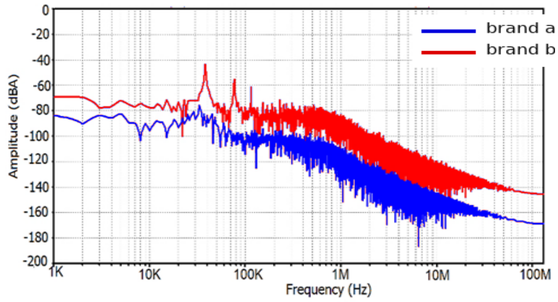


Fig. 11 – Current frequency response at driver output.

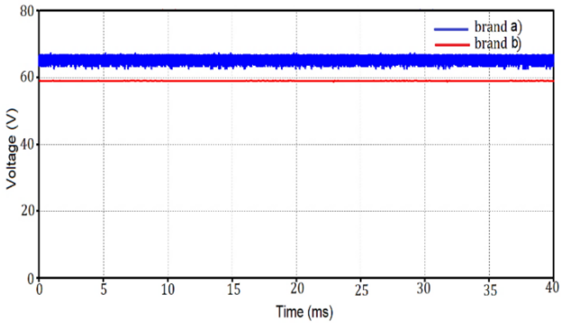


Fig. 12 – Voltage across the driver output.

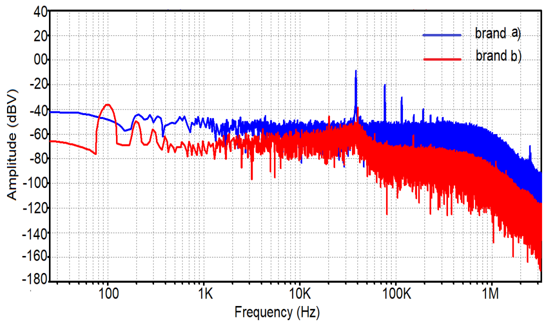


Fig. 13 – Voltage frequency response at driver output.

4.4 COMPARATIVE STUDY OF EMISSIONS BETWEEN THE TWO BRANDS

4.4.1 COMMON MODE

In the common mode, the current flows in all conductors, and the ground returns in the same direction. Figure 14 shows the method of measuring the disturbances conducted in common mode by the amperometric probe [18]

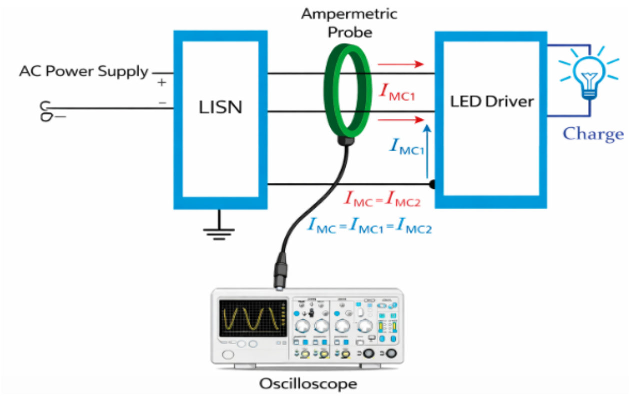


Fig. 14 – Voltage frequency response at driver output.

Figures 15 and 16 show the common-mode electromagnetic interference for both brands. The blue waveform (Brand a) exhibits relatively small fluctuations, indicating a lower level of electromagnetic interference. In contrast, the red waveform (Brand b) presents larger variations and high voltage spikes, revealing a higher level of electrical noise. These disturbances are mainly caused by the high-frequency switching operation inside the LED drivers. The results highlight that the driver design significantly influences the level of conducted EMI. Therefore, Brand a) demonstrates better electromagnetic compatibility performance compared to Brand b).

While in the frequency range, the red curve (Brand B) exhibits higher emission levels across a wide frequency range. In contrast, the blue curve (Brand a) shows lower noise levels and generally remains below the EN55015 QP limit. These results indicate that Brand a) provides better electromagnetic compatibility performance than Brand b).

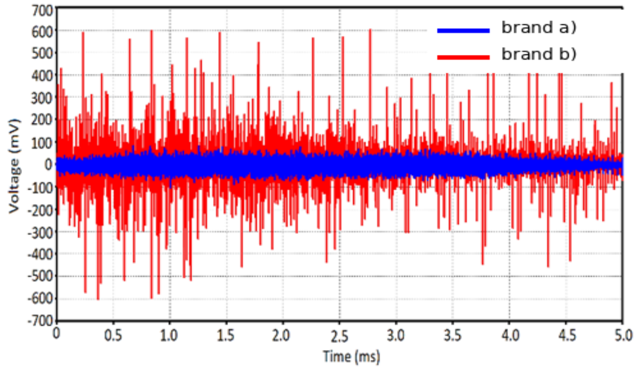


Fig. 15 – Electromagnetic interference conducted in common mode.

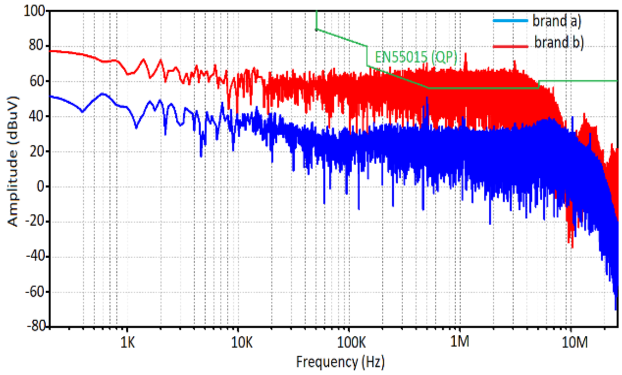


Fig. 16 – Common-mode voltage spectra.

4.4.2 DIFFERENTIAL MODE

In the differential mode, the current flows through a conductor to the victim and back through another conductor in the opposite direction, as shown in Fig. 17, which presents the method of measuring the noise conducted in differential mode [18].

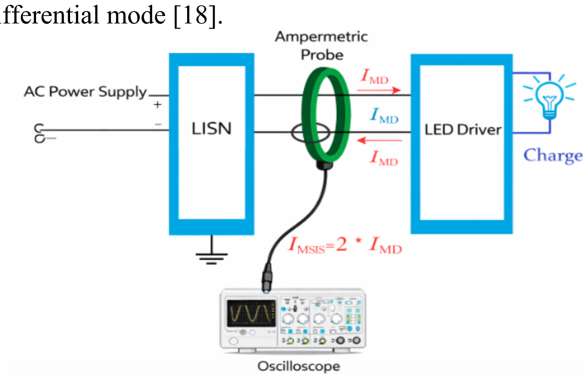


Fig. 17 – Common-mode voltage spectra.

Figures 18 and 19 show the electromagnetic interference in differential mode common to both brands in the time and frequency domains, with very high peaks of electromagnetic disturbance in brand b) TCI, up to 700 mV, while brand b) EMI peaks did not exceed 100 mV. In the frequency domain, the red curve (Brand B) exhibits higher emission levels over a wide frequency range compared to the blue curve (Brand A), indicating stronger conducted disturbances. The green line represents the EN55015 quasi-peak (QP) limit, which defines the maximum allowable emission level for lighting equipment. that the differential mode for both drivers complies with the EN55015 standard limits (quasi-peak) in the 9 kHz-30 MHz frequency band. This spectrum analysis allows the identification of dominant noise components and provides insight into the electromagnetic compatibility performance of the drivers.

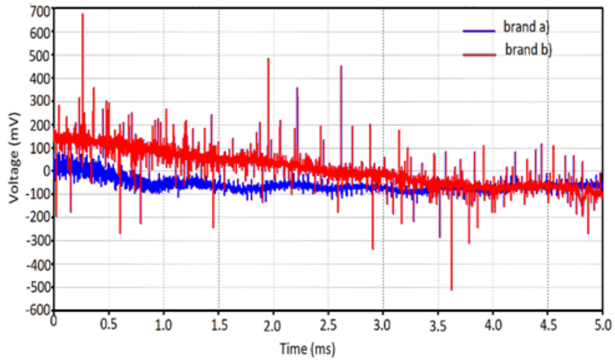


Fig. 18 – Voltage electromagnetic interference in differential mode

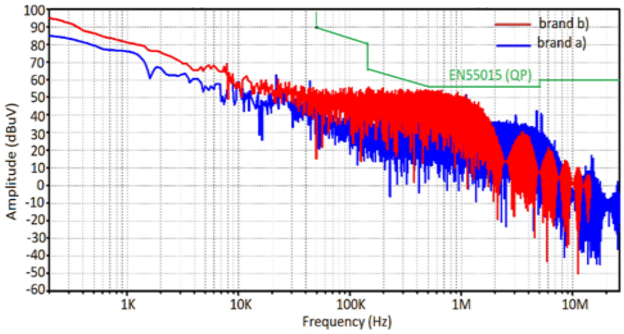


Fig. 19 – Voltage frequency spectra in differential mode.

4.5 COMPARATIVE STUDY OF EMISSIONS IN THE BRAND A) DRIVER TRIDONIK

Figure 18 presents the comparison of the common-mode (CM) and differential-mode (DM) conducted electromagnetic interference generated by the Brand A (TRIDONIC) LED driver. The spectra are plotted over the frequency range from 9 kHz to 30 MHz, with the green curve representing the EN55015 quasi-peak (QP) limit. It can be observed that the emission levels remain below the regulatory limit across the entire frequency band, indicating that the driver complies with EMC conducted emission standards. Moreover, the differential-mode disturbances are more pronounced than the common-mode disturbances in the frequency range between 9 kHz and 200 kHz**.** This behavior is mainly attributed to the switching operation of the power converter inside the LED driver. Overall, the results confirm that the TRIDONIC driver exhibits good electromagnetic compatibility performance.

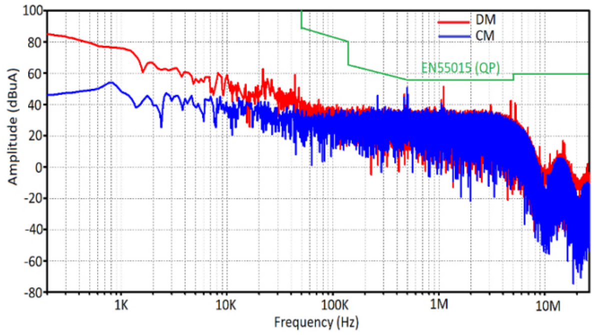


Fig. 20 – Comparison of common and differential electromagnetic interference at brand a) driver TRIDONIC.

6. **CONCLUSION**

The aim of this article is to study and analyze the power quality and conducted emissions generated by the different LED drivers selected in our work, and available on the European market, particularly in Romania, brand a) type TRIDONIC, brand b) type TCI, the two LED drivers are powered by two LED modules of type TCI, the two modules are connected in parallel with a total power of P = 50 W, in the first part, measurements were carried out on the current, input voltage and driver output, as well as the frequency-based current harmonics, where we can conclude that both brands THD complies with the EIC61000-3-2 Class C standard, with ripples more visible in the b)TCI brand Due to the PFC power factor correction, thus stabilizing the current flowing in the LED module. In the second part, measurements are carried out on the electromagnetic interference conducted in common and differential modes in the time and frequency domain for both brands, and the results are compared with each other, as well as with the EN55015 standard limit (quasi-peak). TRIDONIC complied with EN 55015 limits, while the TCI driver exhibited higher common-mode disturbances in the 150 kHz–5 MHz range.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

ABDELHAKIM ZEGHOUDI: experimental framework, visualization, validation, writing – original manuscript preparation.
DORIN LUCACHE: experimental measurements, data analysis, project administration
DRAGOS ASTANEI: experimental measurements, data analysis.
ABDELBER BENDAOUD: review and editing, validation, and visualization
LAURENT CANALE: project administration, visualization.

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