UDC 621.3 https://doi.org/10.20998/2074-272X.2022.4.09

A. Zeghoudi, H. Slimani, A. Bendaoud, B. Benazza, S. Bechekir, H. Miloudi

Measurement and analysis of common and differential modes conducted emissions generated by an AC/DC converter

Introduction. *Rectifiers are the most important converters in a very wide field: the transport of electrical energy in direct current and in the applications of direct current motors. In most electrical and electronic systems, rectifiers are non-linear loads made up of diodes, therefore they are a source of harmonic pollution at a base frequency with a distorting line current signal that generates electromagnetic interference. There are two disturbance modes: common mode and differential mode. These disturbances caused by the rapid variation of current and voltage as a function of time due to the switching of active components, passive components such as inductors, capacitors, coupling, etc.* ***The purpose*** *of this work is to study the conducted emissions generated by a rectifier connected to the Line Impedance Stabilizing Network in an electric circuit. The determination of these disturbances is done for firstly both common and differential modes at high frequency, and secondly harmonics current, line current at low frequency.* ***The novelty*** *of the proposed work consists in presenting a study of disturbance generated by rectifiers using simulation and also experimental measurements at low and high frequencies in order to compare the results.* ***Methods.*** *For the study of the disturbances conducted by the diode bridge converter (rectifier), the sources of conducted electromagnetic disturbances were presented in the first time. Then, the common and differential modes were defined. This converter was studied by LTspice Software for simulation and also experimental measurements at low frequency for harmonics current and high frequencies for disturbances in common and differential modes.* ***Results.*** *All the simulations were performed using the LTspice software and the results obtained are validated by experimental measurements performed in the APELEC laboratory at the University of Sidi Bel-Abbes in Algeria. The obtained results of conducted emissions at high frequency and total harmonics distortion of current at low frequency are compared between simulation and experiment.* References 22, figures 13.

Key words: **electromagnetic disturbances, rectifier, line impedance stabilizing network, common mode, differential mode, simulation, measurement.**

Вступ*. Випрямлячі є найважливішими перетворювачами у дуже широкій сфері застосування: передача електроенергії постійного струму та застосування двигунів постійного струму. У більшості електричних та електронних систем випрямлячі є нелінійними навантаженнями, що складаються з діодів, тому вони є джерелом гармонійних «забруднень» на базовій частоті зі спотворенням сигналу лінійного струму, що генерує електромагнітні завади. Існує два режими завад: загальний та диференціальний режим. Ці завади викликані швидкою зміною струму і напруги в залежності від часу через перемикання активних компонентів, пасивних компонентів, таких як котушки індуктивності, конденсатори, муфти та ін.* ***Метою*** *даної роботи є вивчення кондуктивних випромінювань, створюваних випрямлячем, під'єднаним до мережі стабілізатора повного опору лінії в електричному колі. Визначення цих завад проводиться, по-перше, як для загального, такі для диференціального режимів на високій частоті, а по-друге, для гармонічного струму, лінійного струму на низькій частоті.* ***Новизна*** *запропонованої роботи полягає у поданні дослідження завад, створюваних випрямлячами, з використанням моделювання, а також експериментальних вимірювань на низьких та високих частотах для порівняння результатів.* ***Методи****. Для дослідження завад, створюваних діодним мостовим перетворювачем (випрямлячем), вперше були представлені джерела електромагнітних завад, що виникають. Потім було визначено загальний та диференціальний режими. Цей перетворювач був вивчений програмним забезпеченням LTspice для моделювання, а також експериментальними вимірюваннями на низьких частотах для гармонійного струму та високих частот для завад у загальному та диференціальному режимах.* ***Результати****. Усі моделювання були виконані з використанням програмного забезпечення LTspice, а отримані результати підтверджені експериментальними вимірюваннями, проведеними в лабораторії APELEC в Університеті Сіді-Бель-Аббес в Алжирі. Отримані результати для кондуктивних завад на високій частоті та повних гармонічних спотворень струму на низькій частоті порівнюються стосовно моделювання та експерименту.* Бібл. 22, рис. 13.

Ключові слова: **електромагнітні завади, випрямляч, мережа стабілізатора повного опору лінії, загальний режим, диференціальний режим, моделювання, вимірювання.**

Introduction. With the development of electrical energy installations, more and more static converters are being connected to the electrical network. They inject the electric power supplied by the generators on the network, but unlike the classical electro-technical systems, they also introduce harmonics LF (low frequency) and HF (high frequency) in two different modes (common mode and differential mode). Electromagnetic compatibility (EMC) is one of the major constraints in the design of power electronics structures. In the case of static converters, the switching of semiconductors and their interactions with environmental interference are the main source of conducted disturbances.

Static converters are made up of electronic switches (diode, IGBT, MOSFET) and passive components (inductance, capacitance), and resistors allowing the conversion and/or the regulation of a voltage (or a current). However, electrical conversion systems are sources of electromagnetic pollution due to the frequency of switching of electronic devices, and the rapid variation of voltage and current as a function of time [1-3]. So the main sources of electromagnetic interference (EMI) in power electronics come from switching converters switches and produce essentially conducted and radiated emissions [4-6]. On the basis of their modes of propagation, disturbances can be distinguished into two types: conducted disturbances, which propagate by electrical conduction, and radiated disturbances, which circulate through an electromagnetic field in the air [6, 7].

The most common conducted disturbances are current and voltage harmonics at low frequencies and electromagnetic disturbances either in common mode or in differential mode at high frequencies, harmonic generators are non-linear loads. They don't absorb a sinusoidal current, although they are supplied with a sinusoidal voltage (diode and thyristor rectifiers, discharge lamps, etc) [8-11].

Rate of harmonic distortion at low frequencies. The total harmonic distortion (THD) rate represents the ratio of the effective value of the harmonics to the effective value of the fundamental. It can be concluded that there are no harmonics on the network if the THD is equal to zero. It is defined as:

$$THD = \sqrt{\sum_{n=2}^{\infty}\left(\frac{x_n}{x_2}\right)^2}\,, \tag{1}$$

where x_n is the harmonic component of rank n; x_2 is the second harmonic.

The individual harmonic rate of the current (THD) is defined by the ratio of the amplitude of the n^{th} order harmonic component to the amplitude of the fundamental term component

$$THD_n = \frac{I_1}{I_n}\,, \tag{2}$$

where I_n is the harmonic component of rank n; I_1 is the fundamental harmonic.

Figure 1 shows a distorted input current signal due to the non-linear load, due to the presence of the third order harmonic of frequency 150 Hz.

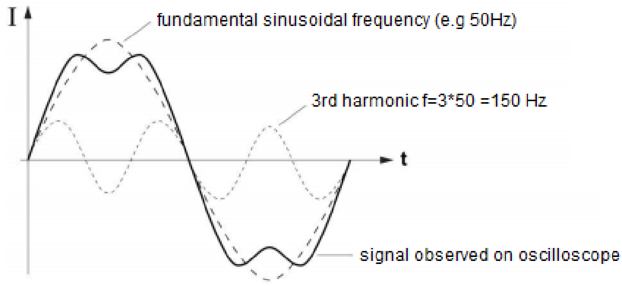

Fig. 1. Input current distortion due to non-linear load [12]

Conducted disturbances in power electronic devices. Various studies [12-16] on conducted electromagnetic pollution have presented measurement techniques in the different types of converters. In [12] the disturbances generated by the chopper are determined in common and differential mode with simulation and experimental. Thus, the interference generated in an inverter fed AC motor [13, 14], in our work we have determined the emissions conducted at LF (odd harmonics) and HF (common mode and differential mode) generated by a single-phase diode bridge in the time approach and frequency approach. The temporal approach uses LTspice circuit simulation software and the noise spectrum is obtained by a fast Fourier transform (FFT) [17, 18].

The emissions conducted at HF subdivides has two categories. The emissions in common mode are generated by the flow of current that propagates in all conductors in the same direction and the return is through the ground or ground plane. This tendency is mainly due to parasitic capacitances in the system that are sensitive to voltage variations and products dv/dt on the lines, and the second category is the differential mode. They are caused by the flow of current that propagates in one conductor in a direction and return in the other conductor in the opposite direction. This current is mainly due to parasitic inductances of the system, which are sensitive to variations in the current di/dt generated on the conductors [19-22].

Figure 2 illustrates the EMI measurement setup in a diode bridge rectifier AC/DC converter with LF. As shown in Fig. 2 in order to visualize the line current and the source voltage, and to determine the odd harmonics generated by the diode bridge rectifier.

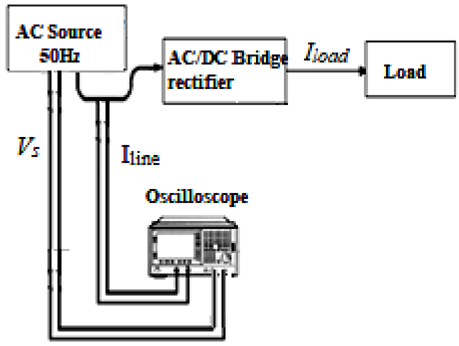

Fig. 2. Descriptive diagram of the single-phase rectifier experimental bench at LF

The second part of the measurement is devoted to the HF conducted emissions, as shown in Fig. 3. The line impedance stabilizing networks (LISN) was inserted between the source and the rectifier. An equivalent circuit for the LISN is shown in Fig. 2. The LISN was used to stabilize the input line impedance and to ensure that the measurement results are only related to the equipment under test without influence of the line impedance [13]. The LISN is connected to a 50 Ω termination or to a spectrum analyzer with an input impedance of 50 Ω. A voltage drop across either 50 Ω impedance constitutes the total conducted noise voltage.

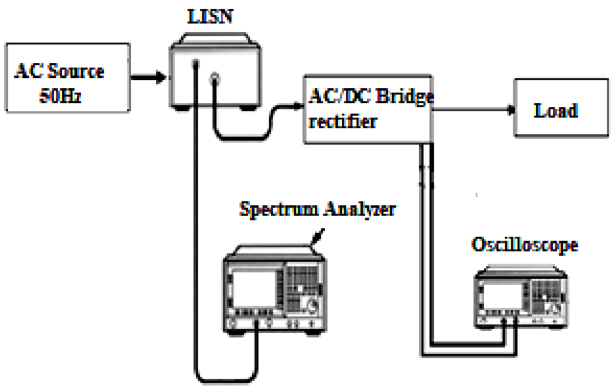

Fig. 3. Descriptive diagram of the single-phase rectifier experimental bench at HF

Study of the disturbances of the AC/DC converters. As long as the line current is positive, energy is supplied by the network, which allows the capacitor to charge. As soon as this current is cancelled, the diodes are blocked. The load and the network are then disconnected, which causes the capacitor to discharge into the resistor. The study of electromagnetic disturbances in static AC/DC converter is done in two steps: study of LF and HF disturbances.

Study of LF disturbances. Simulation of the single-phase diode bridge rectifier. The single-phase rectifier circuit simulated by LTspice Software (Fig. 4) has the following data: V_{res} = 25 V; L_{res} = 600 µH; R_{res} = 0.4 Ω; f = 50 Hz; C_{ch} = 940 µF; R_{ch} = 82 Ω.

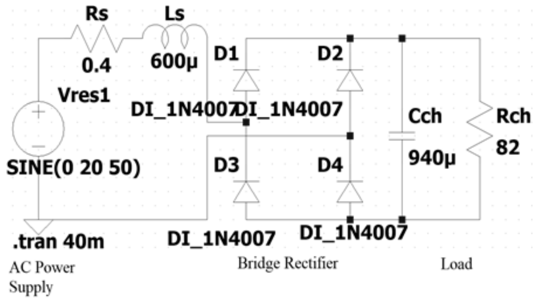

Fig. 4.Diode bridge delivering on a load (LF model)

Experimental measurements. Figures 4, 5 represent respectively the descriptive diagram and a photograph of the experimental bench that has been realized representing the single-phase rectifier of type PD2 based on the rectifier diodes 1N4007.

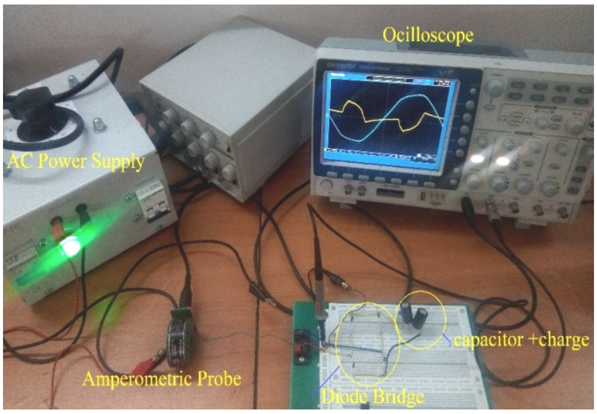

Fig. 5. Photo of the measurement bench of the electromagnetic disturbances generated by a single-phase rectifier in diode bridge

Figures 6, 7 illustrate respectively the voltage at the bridge terminals and the line current I_{lin} that we obtained by simulation and by experimental measurement.

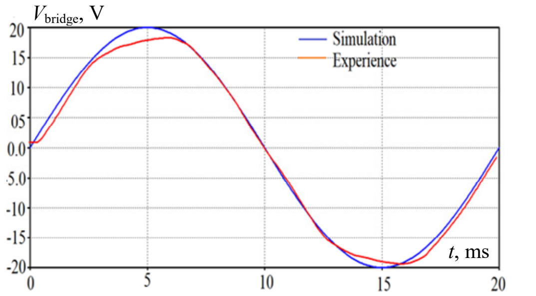

Fig. 6. Voltage at the terminals of the diode bridge V_{bridge}

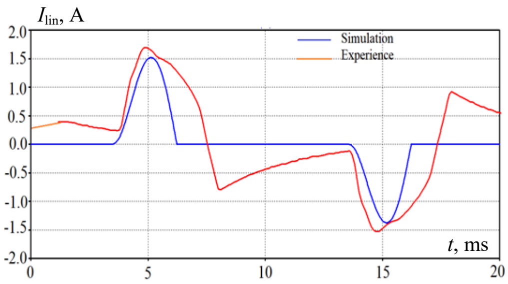

Fig. 7. Line current in the single-phase rectifier I_{lin}

From the voltage at the terminals of the bridge V_{bridge} represented in Fig. 6 and the current of the line I_{lin} represented in Fig. 7 we notice a concordance between the simulation and the measurements, the curves of simulation and measurements are not purely sinusoidal. They present deformations on the voltage at the input of the converter and the current requested by the converter is a periodic signal of period rigorously identical to the initial sinusoid but of very different form because of the non-linear load.

Figure 8 shows the frequency spectrum of the line current I_{lin} that we obtained by simulation and by experimental measurement.

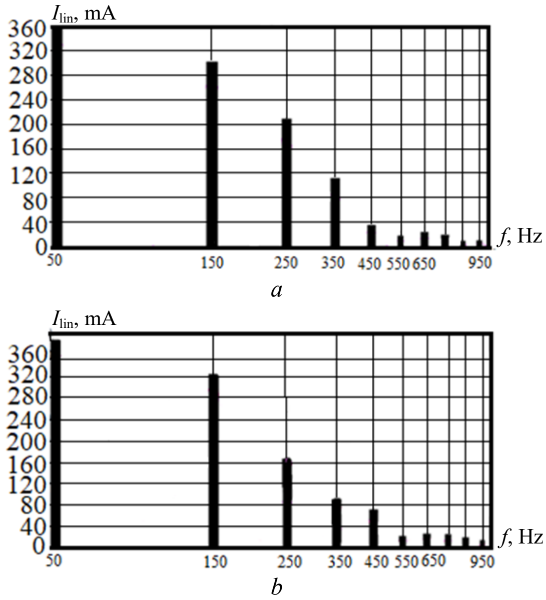

Fig. 8. Line current spectrum:
a) simulation results; *b*) experimental results

From the experimental results obtained, we find that it has a good agreement with those of the simulation. The analysis of the results shows that the amplitudes of the odd LF harmonics of the line current in the case of a single-phase rectifier are larger because the rectifiers (non-linear loads) are sources of harmonics.

Figure 9 shows the temporary variations of the rectified voltage across the load that we obtained by simulation and experimental measurement.

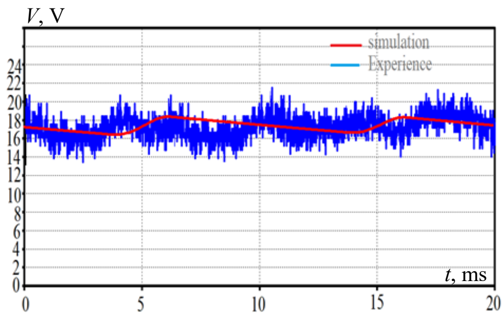

Fig. 9. Rectified voltage at the terminals of the load

Figure 10 shows the frequency variation of the rectified voltage across the load that we obtained by simulation and experimental measurement.

From Fig. 9 we notice a ripple in the rectified voltage, this ripple shows the charge and discharge of the capacitor. In Fig. 10, we notice the harmonics at LF because of the non-linear charge. Thus a resonance peak at 10 kHz, after this resonance frequency there is a slight disturbance.

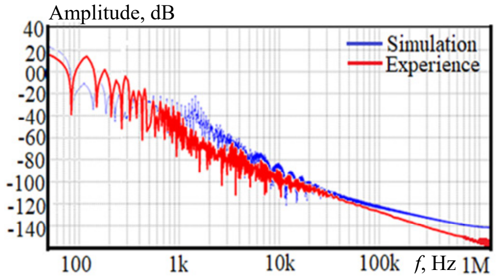

Fig. 10. Frequency variation of the rectified voltage across the load

Study of HF disturbances. All equipment with switching power components produces and emits HF noise. This noise can interfere with the reception of useful signals and can cause system and equipment malfunctions.

In this section, we will present the two main modes of propagation for EMI: the differential mode and the common mode. The disturbances are measured by using the LISN. Two quantities have all the information concerning the diode bridge and the load: the line current and the voltage across the bridge.

Simulation of a single-phase bridge rectifier with LISN. We consider a single-phase rectifier with a LISN and a resistance R_C for load. The circuit of Fig. 11 has the following data: V_{res} = 20 V; f = 50 Hz; C_{ch} = 940 µF; R_{ch} = 82 Ω.

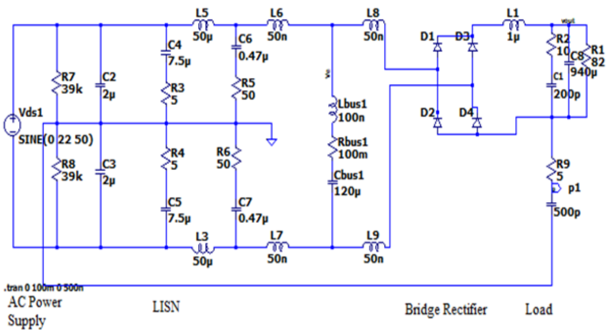

Fig. 11. Diagram of a single-phase diode rectifier with the LISN under LTspice software

Experimental measurements. After the realization of the single-phase diode bridge rectifier, we connected it in series with the LISN, in order to measure the electromagnetic disturbances, as it is presented in Fig. 3.

Study of the disturbances in differential mode. Figure 12 illustrates the frequency variations of the voltage across the LISN equivalent measurement resistor, which represents the current image of the differential mode disturbances generated by the diode bridge.

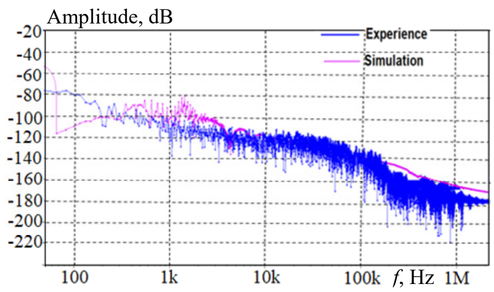

Fig. 12. Spectrum of localized differential disturbances on LISN

From the results of Fig. 12 we note that at the blocking of the diodes an oscillatory phenomenon of a frequency and important amplitude appears. This phenomenon is similar to the voltage jump at the end of the encroachment of the bridge diodes. A similar resonance and the same resonance frequency appear on the spectrum of the AC voltage of the bridge.

Study of the disturbances in common mode. The common mode disturbances were measured in order to compare them with the simulation. In Fig. 13, the results of the frequency variation (common mode current), obtained by simulation and by experimental measurement, are presented.

The results of Fig. 13 present the spectrum of the current in common mode, where we notice an oscillatory phenomenon of a frequency and important amplitude that appears and also a resonance.

By comparing the results of the current spectrum of the two modes, it can be seen that the common mode current spectrum is very high compared to the differential mode current.

In practice, in order to minimize the effect of the common mode current on the differential mode current, the semiconductor radiators and the load ground plane are isolated from the converter ground plane. In reality, the HF behavior of the load requires a more complex analysis of the EMI propagation paths [1].

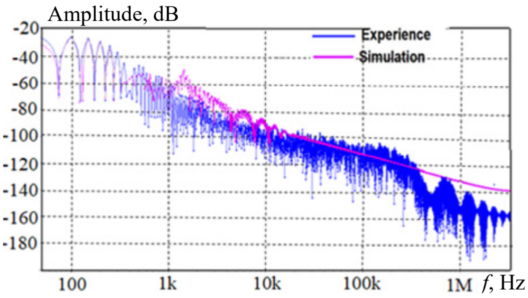

Fig. 13. I_{CM} common mode current spectrum

Conclusions.

1. Considering the importance of the determination of the conducted disturbances generated by the static converters AC/DC in the electric systems, it was decided to carry out this study which is based on the use of the simulation and also the realization of an experimental bench to quantify this emission in the two common and differential modes.

2. From the results obtained, it has been proved practically that the disturbances in common mode are very high compared to the disturbances in differential mode, which requires the use of reduction means in order to weaken or eliminate this type of disturbance, which will be addressed in other future works.

3. The AC/DC converter was studied by LTspice Software for simulation and also experimental measurements at low and high frequencies in order to compare the results. We notice the harmonics at low frequency because of the non-linear charge. Thus a resonance peak, after this resonance frequency there is a slight disturbance.

Conflict of interest. The authors declare that they have no conflicts of interest.

REFERENCES

1. Slimani H., Zeghoudi A., Bendaoud A., Reguig A., Benazza B., Benhadda N. Experimental Measurement of Conducted Emissions Generated by Static Converters in Common and Differential Modes. *European Journal of Electrical Engineering*, 2021, vol. 23, no. 3, pp. 273-279. doi: https://doi.org/10.18280/ejee.230312.

2. Zeghoudi A., Bendaoud A., Canale L., Tilmatine A., Slimani H. Common Mode and Differential Mode noise of AC/DC LED Driver. *2021 IEEE International Conference on Environment and Electrical Engineering and 2021 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, 2021, pp. 1-6. doi: https://doi.org/10.1109/EEEIC/ICPSEurope51590.2021.9584616.

3. Miloudi M., Bendaoud A., Miloudi H. Common and differential modes of conducted electromagnetic interference switching power converters. *Revue Roumaine des Sciences Techniques Serie Electrotechnique et Energetique*, 2017, vol. 62, no. 3, pp. 246-251.

4. Miloudi M., Bendaoud A., Miloudi H., Nemmich S. Etude et Réduction des Emissions Conduites Générées par l'Alimentation à Découpage (SMPS). *Conférence national sur l'inductique. CI'03*, Tizi–Ouzou, Algérie, April 2013. (Fra).

5. Fakhfakh L., Ammous A. New simplified model for predicting conducted EMI in DC/DC converters. *Electrical Engineering*, 2017, vol. 99, no. 3, pp. 1087-1097. doi: https://doi.org/10.1007/s00202-016-0474-2.

6. Miloudi M., Bendaoud A., Miloudi H. Characterization of Conducted Electromagnetic Interference (EMI) Generated by Switch Mode Power Supply (SMPS). *International Electrical Engineering Conference*, Nov. 2012, Batna, Algeria.

7. Song Zhenfei, Su Donglin, Dai Fei, Duval F., Louis A. A novel electromagnetic radiated emission source identification methodology. *2010 Asia-Pacific International Symposium on Electromagnetic Compatibility*, 2010, pp. 645-648. doi: https://doi.org/10.1109/APEMC.2010.5475803.

8. Costa F., Rojat G. CEM en Electronique de Puissance, Sources de Perturbations, Couplage, SEM. *Techniques de l'ingénieur, Traité Génie Electrique*, D 3290, 15 Août, 2008. (Fra).

9. Hanzelka Z., Bien A. *Guide Power Quality, Section 3: Harmoniques*. Leonardo Energy, Edition Août 2007, AGH University of Science and Technology.

10. Zeghoudi A., Bendaoud A., Canale L., Tilmatine A., Slimani H. Determination of Power Factor and Harmonic Distortion of AC/DC LED Driver. *2021 IEEE International Conference on Environment and Electrical Engineering and 2021 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, 2021, pp. 1-6. doi: https://doi.org/10.1109/EEEIC/ICPSEurope51590.2021.9584665.

11. Roger C. Dugan, Surya Santoso, Mark F. McGranaghan, H. Wayne Beaty. *Electrical Power System Quality*. McGraw Hill Professional, 2002. 528 p.

12. Zeghoudi A., Bendaoud A., Slimani H., Benazza B., Bennouna D. Determination of electromagnetic disturbances in a buck chopper. *Australian Journal of Electrical and Electronics Engineering*, 2022, vol. 19, no. 2, pp. 149-157. doi: https://doi.org/10.1080/1448837X.2021.2023073.

13. Miloudi H., Bendaoud A., Miloudi M. Réduction des perturbation électromagnétique conduites dans la machine asynchrone. *Mediterranean Journal of Modeling and Simulation*, 2014, vol. 2, no. 1, pp. 8-15.

14. Miloudi H., Bendaoud A., Miloudi M., Gourbi A., Slimani H. Common Mode conducted electromagnetic interference in inverter fed-AC motor. *Przeglad Elektrotechniczny*, 2010, vol. 86, no. 12, pp. 272-275.

15. Miloudi M., Miloudi H., Bendaoud A., Salhi M.A., Al-Omari A.N. Experimental characterization of the high-frequency isolating power transformer. *Elektrotehniski Vestnik/Electrotechnical Review*, 2019, vol. 86, no. 4, pp. 211-218.

16. Chikhi N., Bendaoud A. Evaluation of Conducted Disturbances Generated by the Chopper-rectifier Association Propagating to the Electrical Network. *European Journal of Electrical Engineering*, 2019, vol. 21, no. 1, pp. 1-6. doi: https://doi.org/10.18280/ejee.210101.

17. Tarateeraseth V., Maio I.A., Canavero F.G. Assessment of Equivalent Noise Source Approach for EMI Simulations of Boost Converter. *2009 20th International Zurich Symposium on Electromagnetic Compatibility*, 2009, pp. 353-356. doi: https://doi.org/10.1109/EMCZUR.2009.4783463.

18. Fakhfakh L., Ammous A. New simplified model for predicting conducted EMI in DC/DC converters. *Electrical Engineering*, 2017, vol. 99, no. 3, pp. 1087-1097. doi: https://doi.org/10.1007/s00202-016-0474-2.

19. Leitungstheorie B., Moschytz G.S., Brugger U., Rosenblatt J. *Transmission on Lines*. 1998. 61 p. Available at: http://ivanlef0u.fr/repo/madchat/coding/electro/Transmission%2520sur%2520lignes.pdf (accessed 10 May 2021).

20. Angénieux G. *Transmission Lines in Harmonic and Transient Regime*. University of Savoy, France, 2009.

21. Montrose M.I. *Printed circuit Board Design Techniques For EMC Compliance. A Handbook for Designers, 2nd Edition*. Wiley-IEEE Press, 2000, 336 p.

22. Wang S. *Characterization and Cancellation of High-Frequency Parasitics for EMI Filters and Noise Separators in Power Electronics Applications*. Thèse de Doctorat, Faculté de l'Institut polytechnique de Virginie, May 2002. Available at: http://hdl.handle.net/10919/27885 (accessed 15 July 2021).

Received 12.02.2022
Accepted 18.04.2022
Published 20.07.2022

Abdelhakim Zeghoudi[1], *PhD,*
Helima Slimani[1,2], *Lecturer,*
Abdelber Bendaoud[1], *Professor,*
Baghdadi Benazza[3], *Lecturer,*
Seyfeddine Bechekir[4], *PhD,*
Houcine Miloudi[1], *Lecturer,*
[1] Laboratory of Applications of Plasma, Electrostatics and Electromagnetic Compatibility (APELEC),
Djillali Liabes University of Sidi Bel-Abbes, Algeria,
e-mail: hakooumzeghoudi@gmail.com,
babdelber@gmail.com (Corresponding author);
el.houcine@yahoo.fr
[2] University of Tiaret, Algeria,
e-mail: Slimani.Halima@yahoo.fr
[3] University of Ain Temouchent, Algeria,
e-mail: benazza13@yahoo.fr
[4] Intelligent Control and Electrical Power Systems (ICEPS) Laboratory, Department of Electrical Engineering,
Djillali Liabes University, Sidi Bel-Abbes, Algeria,
e-mail: seyfeddine.electrotechnique@gmail.com

How to cite this article:
Zeghoudi A., Slimani H., Bendaoud A., Benazza B., Bechekir S., Miloudi H. Measurement and analysis of common and differential modes conducted emissions generated by an AC/DC converter. *Electrical Engineering & Electromechanics*, 2022, no. 4, pp. 63-67. doi: https://doi.org/10.20998/2074-272X.2022.4.09