Annals of the University of Craiova, Electrical Engineering series, No. 43, Issue 1, 2019; ISSN 1842-4805

Operational Aspects of an Auxiliary Converter Used in Railway Applications

Radu Florin Marinescu, Adrian Hurezeanu, Petre Marian Nicolae, Diana Cristina Marinescu
University of Craiova , Dept. of Electrical Engineering, Aeronautics and Energetics
rmarinescu@elth.ucv.ro, adrian.hurezeanu@cesiautomation.ro, pnicolae@elth.ucv.ro, maria.diana_cristina@yahoo.com

Abstract – **This paper presents operational aspects of an auxiliary converter for rail traction which was designed, simulated and realized by authors under the frame of an academia-industry project based partnership. The general technical and functional characteristics of the equipment are described. Data representing electrical waveforms acquired from the realized converter's key test points are presented. High harmonic orders (exceeding the 70-th rank) had to be removed through original programs in order to reveal the significant low harmonic order components. The instantaneous values representing the pollution with harmonic orders were evaluated, along with the components oscillating at the fundamental frequency. Highly variable levels of noise were revealed. Unlike the current waveforms from the analyzed converter's output, the phase voltages preserved a significant content of harmonic distortions after the removal of harmonics higher than 70. Therefore an analysis based on the Fast Fourier Transform was performed. Most significant power quality indices were computed for cutoff frequencies corresponding to the harmonics from the set {40, 70 and 80}. Harmonic spectra for phase currents, voltages, active and reactive powers were also represented, along with the phasor diagram. Filtering of all frequencies over the 40-th harmonic was revealed to be a good solution for electromagnetic compatibility compliance.**

Cuvinte cheie: *convertor auxiliar, aplica□ii feroviare, indicii de calitate a puterii, filtrare armonică*

Keywords: *auxiliary converter; railway applications; power quality indices, harmonics filtering*

I. INTRODUCTION

Simultaneous with the electrification of rail transportation systems, the amount of additional electric systems in vehicles has increased substantially [1]. The term "auxiliary systems" is used to define all the systems on a railway vehicle meant to accomplish “non-traction” functions. Nowadays, many auxiliary systems accompany the railway vehicles (e.g. lighting systems, compressors, pumps, air conditioning etc.) To supply power to the auxiliary systems, an auxiliary power supply unit converts the voltage from the overhead line to the levels required by the supply voltages. The total demand for auxiliary energy is usually between x 10 kW and x 100 kW [2]-[4].

For more than 25 years, the modern trends concerned with power converters meant to supply auxiliary services used in railway applications have been focussed on requirements like: small sizes and weight, increased efficiency and simplified maintenance [4]-[6]. Due to the increasing number of electronic loads which require high quality energy under the circumstances of increased running distances for locomotives, increasing the reliability of these devices became a priority [7]-[9].

After a short introduction, the 2-nd section is dedicated to a brief description of the studied auxiliary converter (AuC), whilst the 3-rd one provides useful information on the initial design data and operational characteristics of AuC. Relevant data tables and pictures with the realized AuC and the portable data acquisition system used to acquire data from key test points are included in the 4-th section. The same section presents significant acquired voltage and current waveforms, with or without noise, including all components of frequency or revealing few categories of them. Interesting results of the power quality analysis are presented in the 5-th section and afterward conclusions are drawn.

II. AUXILIARY CONVERTER DESCRIPTION

Depending on the type of railway vehicle, the types of consumers connected to the output of a train converter for auxiliary services (referred from this point on as „auxiliary converter”) can be grouped as follows [10]...[15]: (a) cabin air conditioning equipment;(b) equipment for air conditioning passenger cars; (c) main compressor power supply; (d) supplying utility for traction motor fans; (e) transformer fan supply, inductances, braking resistors;(f) supplying fans of electrical equipment; (g) supplying oil pumps and cooling pumps;(h) powering d.c. consumers

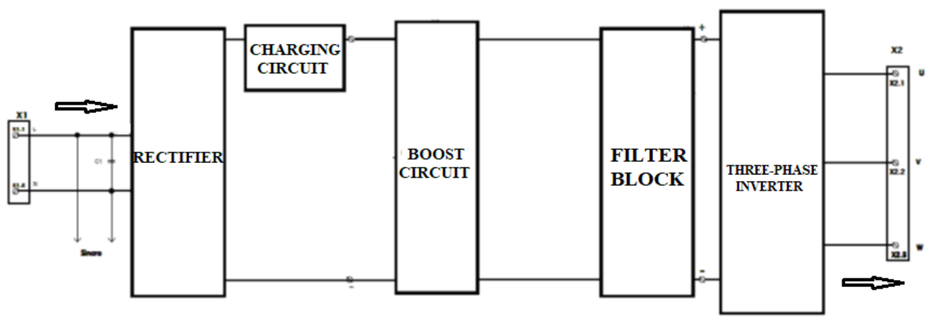


Fig.1. Block diagram of the auxiliary converter

and charging battery (control equipment, lighting etc.);(i) supplying sockets from the passenger compartments.

The auxiliary converter studied in this paper contains 5 main elements: a rectifier, a charging circuit, a boost circuit, a filter block and a three-phase inverter. The block diagram of the auxiliary converter is shown in Fig. 1. The main operational characteristics of the equipment are: (a) supplying voltage: 380 V ac.; (b) frequency of supply voltage: 50 Hz ± 2 %; (c) adjustable output voltage: 3 x 0....400 V ac; (d) adjustable output frequency: 1 ... 500 Hz.

III. Initial Design Data and Operational Characteristics of the Auxiliary Converter

In order to design the auxiliary converter, in the first stage, the power semiconductor elements were selected based on the results yielded by the calculation of characteristic quantities [15]. These quantities depend on the static converter in which the semiconductor switching elements will operate. The following factors had to be considered: (a) static converter type; (b) nominal values of the voltage and load current; (c) control range. The main initial data considered as starting point for the designing stage are gathered by Table I [15].

The authors presented in [15] detailed information on the designing of the following components belonging to the AuC whose behavior is addressed in this paper: (a) the switching electrical block which, supplied from the single-phase voltage, provides functionality characterized by an appropriate power factor; (b) the d.c. link filter; (c) the static converter; (d)the control unit accomplishing: data acquisition, displaying diagrams and data transmission.

A MATLAB/SIMULINK model was afterward conceived in order to simulate the operation of the designed auxiliary converter [15]. The simulations validated the initial design correctness and allowed for the practical realization of the designed converter. The main operational characteristics of the auxiliary converter realized according to the design are gathered by Table II [15].

IV. Monitoring and Filtering Significant Waveforms Acquired from the Auxiliary Converter

A portable data acquisition system (DAS) was used to record information on significant waveforms acquired from the designed and realized auxiliary converter (Fig. 2) [15].

TABLE I.
INITIAL DATA

Type of quantity / characteristic	Required value/prescription
Supply Voltages	380 Va.c
Total rated output power	45 kW
Output voltages	Three-phase, 3x400V/50Hz, sinusoidal
	Single phase, 1x230V/50Hz, sinusoidal
	24V d.c./15kW
Equipment placing	Inside vehicles or under the floor

TABLE II.
OPERATIONAL CHARACTERISTICS

Type of quantity / characteristic	Required value / prescription
Separation / coupling of the power supply network	d.c. fuses, connectors
Maximum absorbed current	Max 1.2 x In
Efficiency	>95%
Electromagnetic disturbances	minimum
Connection possibilities for installation, commissioning and maintenance	Easy access

It recorded voltages and currents from the test stand and power quality indices were evaluated in order to see if any special measures are to be taken in order to obey the requirements imposed by the standards in force.

The used DAS is able to generate a database with sequences of recordings acquired at predefined time intervals. Dedicated software algorithms were conceived, in order to identify the technical solutions for optimizing the operational parameters, reduce the energy consumption and implicitly reduce the costs.

Fig. 3 depicts the realized converter. Fig. 4 represents an instantaneous picture acquired during the mounting of transducers used during data acquiring.

Fig. 2. Portable data acquisition system used to acquire data.

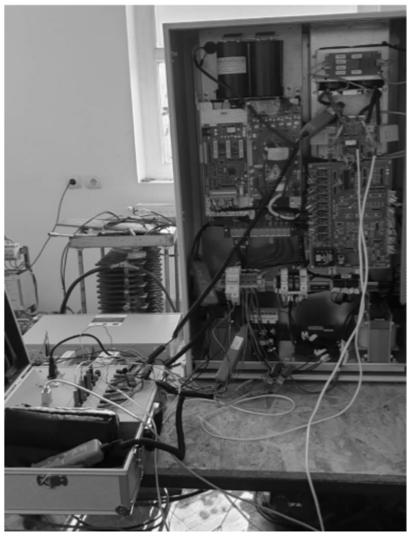


Fig. 3. The auxiliary converter.

Fig. 4. Current and voltage transducers mounting.

In Fig. 5, the left pictures represent sequences from the initial acquired waveforms, interpolated such as to have a number of components equal to a power of 2. This condition was imposed by the algorithms used to process data. The middle pictures represent the waveforms without harmonic orders higher than 70 whilst the right pictures represent the removed components, corresponding to harmonic orders higher than 70.

Fig. 6 depicts the phase voltages and currents at the output of the auxiliary services converter, after a spline interpolation of the data acquired by DAS. Fig. 7 is dedicated to the same electrical waveforms, after removing the harmonics higher than 70. In Fig. 7 the dark lines represent the component oscillating at fundamental frequency, evaluated with the Stationary Wavelet Transform.

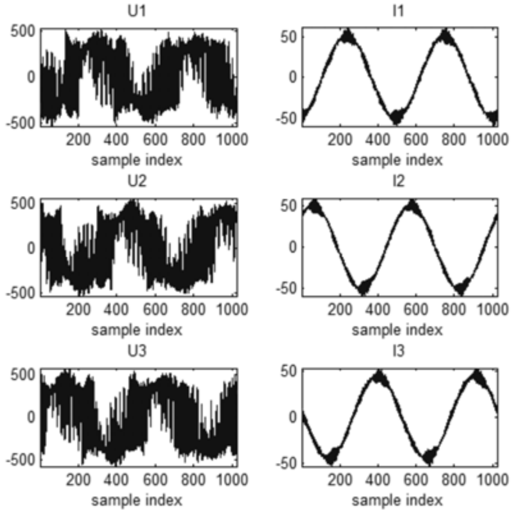


Fig. 6. Interpolated phase voltages and currents at the output of the auxiliary services converter.

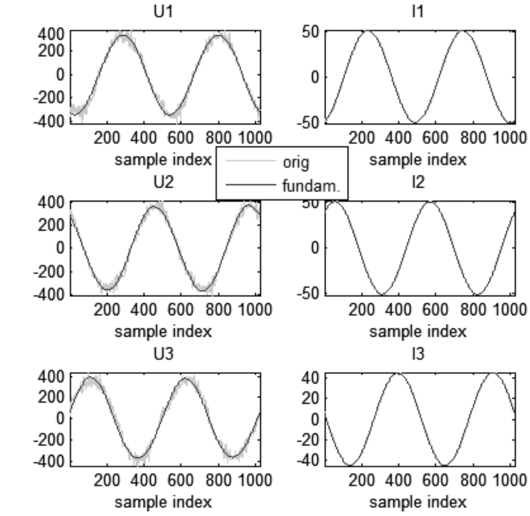


Fig. 7. Voltages (left) and currents (right) waveforms at the output of the auxiliary services converter without harmonics higher than 70 and fundamental component represented in red.

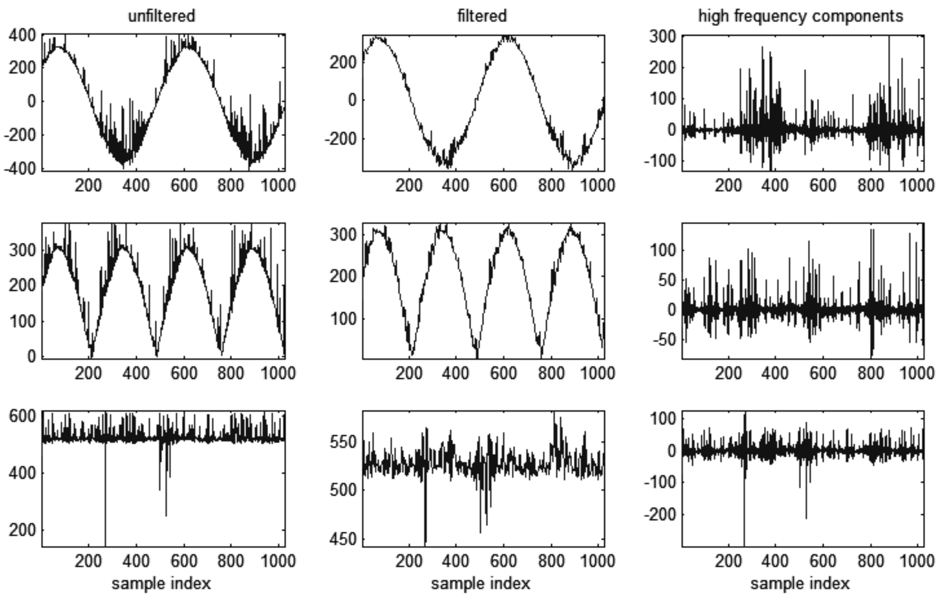


Fig. 5. Top - supply voltage; middle - rectified voltage ; bottom - boost converter voltage.

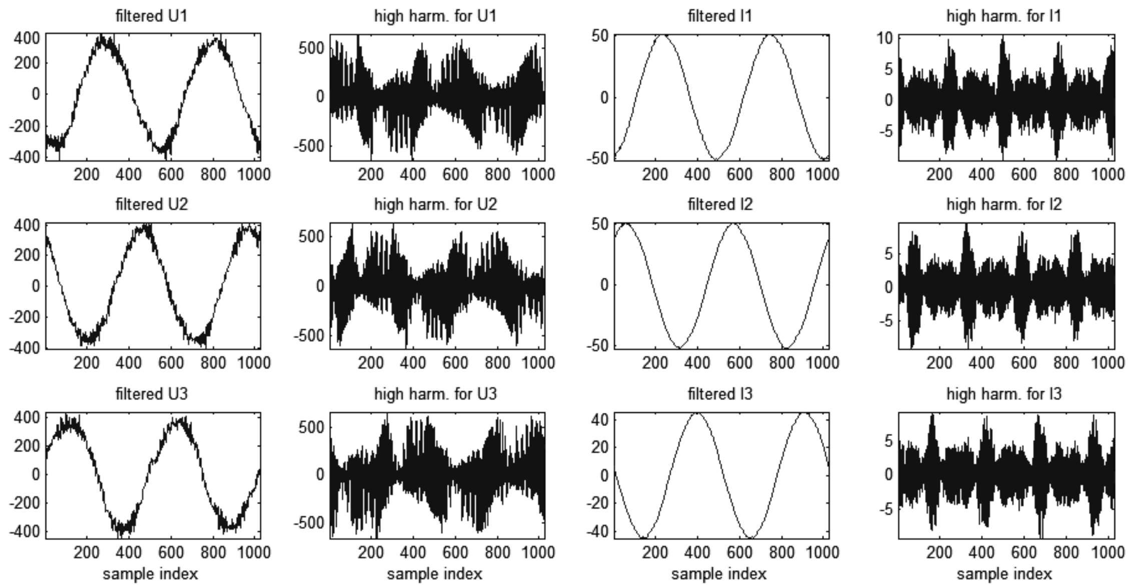


Fig. 8. Voltages and currents from the auxiliary converter output after removing the harmonics higher than 70, along with the instantaneous variation of the removed component

The instantaneous variations of the component removed by filtering the harmonic components higher than 70 are depicted by Fig. 8. Whilst the filtered currents look "almost sinusoidal" and exhibit an acceptably low content of harmonic components after filtering (Fig. 9) the voltages distorting residues remained significant and therefore the cutoff frequency for the filtering process had to be reconsidered.

V. Power Quality Analysis

Considering the preliminary evaluations of the acquired signals presented in the previous section, an analysis of the auxiliary services converter's ouput signals relative to power quality became compulsory. Therefore original programs, relying on the Fast Fourier Transform (FFT) were employed [16],[17]. Due to the strong electromagnetic noise polluting the industrial environment in which the measurements were made, it was necessary to pre-filter the high order harmonics, from the frequency range of noise.

Also, as revealed in the previous section, the voltages at the auxiliary service converter`s output were proved to be polluted by a significant amount of low order harmonics. Their filtering became compulsory and therefore different cuttoff limits were used.

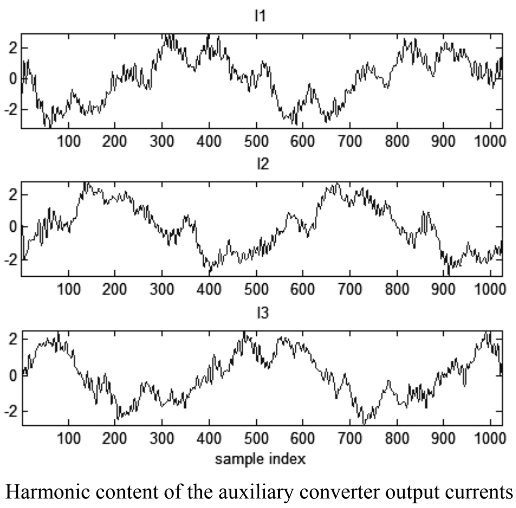


Fig. 9. Harmonic content of the auxiliary converter output currents after filtering the harmonics higher than 70.

Fig. 10 depicts the auxiliary converter's filtered output voltages when the highest harmonic order was set to another two distinct values: 80 and 40.

Fig. 11 depicts the auxiliary converter output's filtered current and voltage harmonics for all three analyzed cases, for the the cutoff frequencies corresponding to the 80-th, 70-th and 40-th harmonic orders. Fig. 12 represents the harmonic spectra of the active and reactive powers when filtering the harmonics higher than 40. The 1-st harmonic (for fundamental frequency) is not fully represented (100%) in order to have a more clear representation of the remaining harmonics.

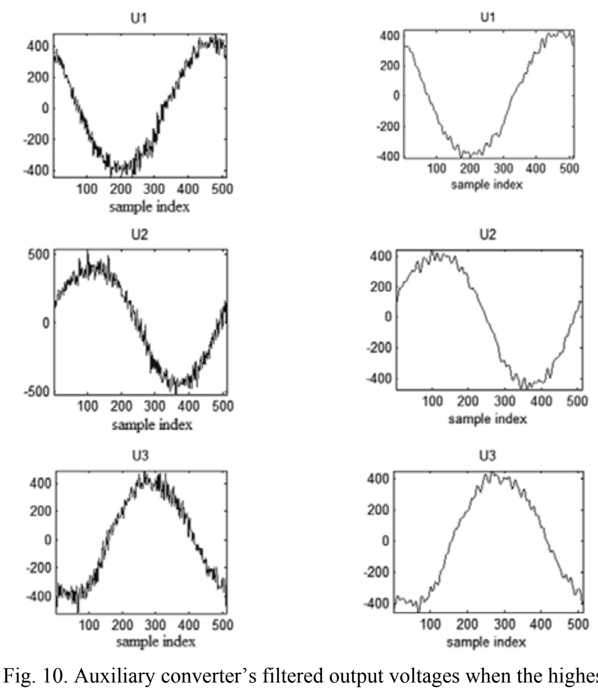
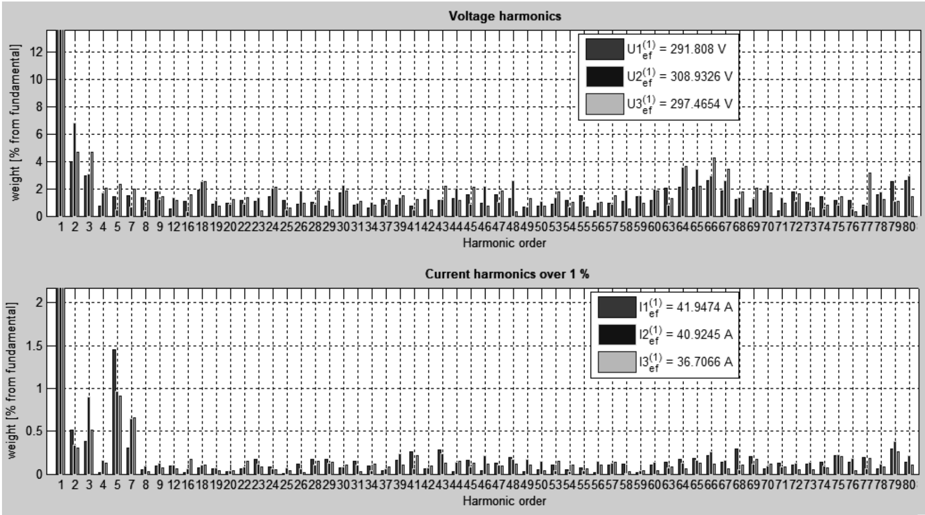
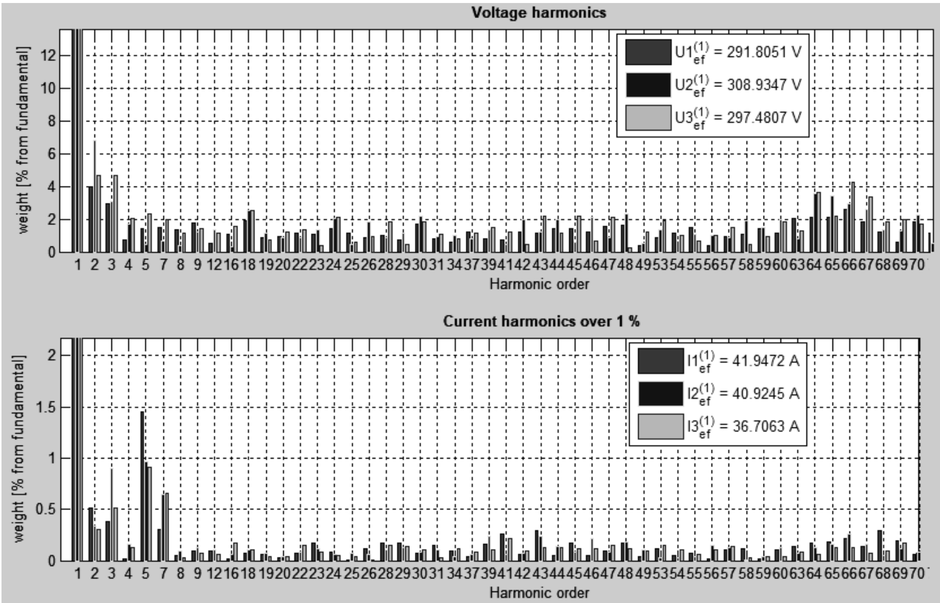


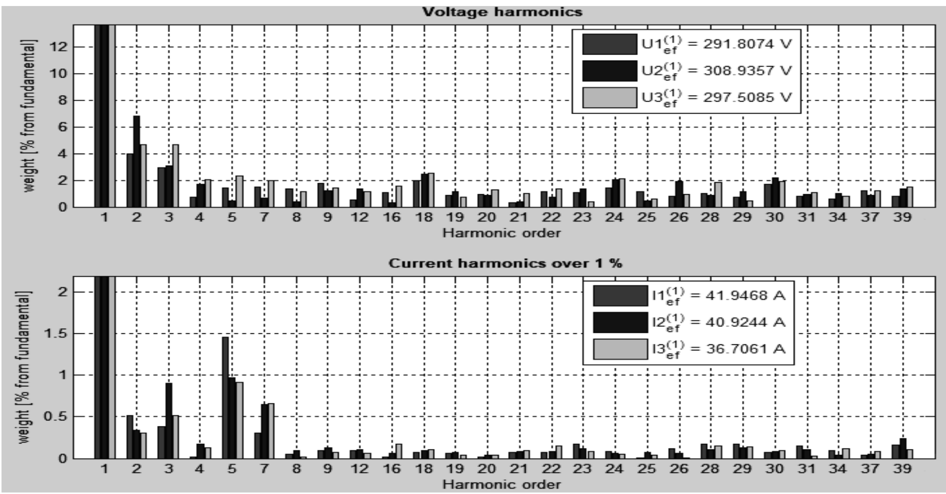
Fig. 10. Auxiliary converter's filtered output voltages when the highest harmonic order was set to the 80-th harmonic (left) and to the 40-th harmonic (right).



(a)



(b)



(c)

Fig. 11. Auxiliary converter output's filtered current and voltage harmonics for three cutoff frequencies: (a) 80-th harmonic; (b) 70-th harmonic and (c) 40-th harmonic.

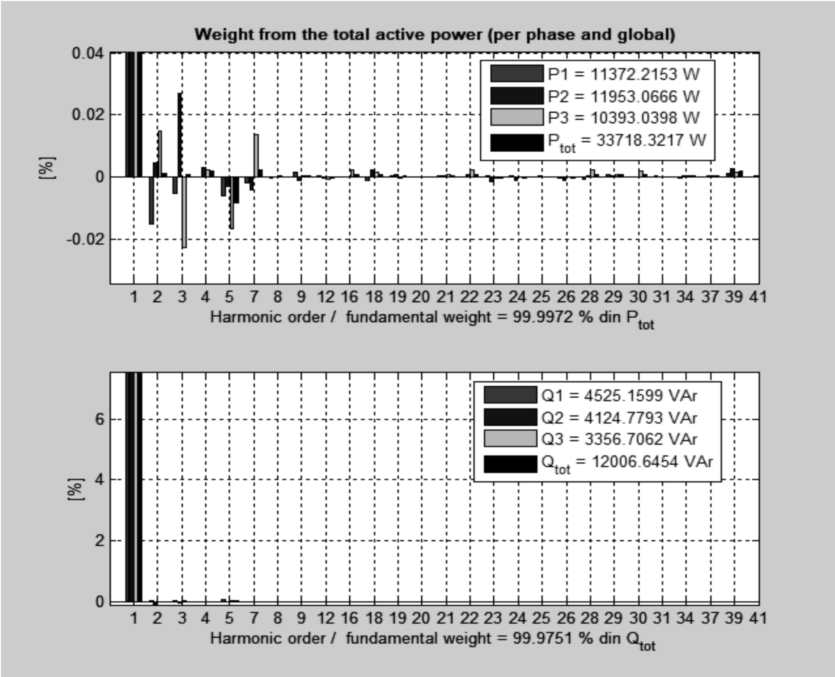


Fig. 12. Auxiliary converter output's active and reactive powers commputer with currents and voltages filtered with a cutoff frequency equal to the 40-th harmonic.

Table III gathers the values of certain significant power quality indices for the auxiliary converter's filtered output phase voltages when considering the 3 different cutoff harmonic orders mentioned above. The highest cutoff harmonic order for which the limits for THDU were obeyed was found to be equal to 40. Taking into account the limits imposed by the standards for power quality indices, it was concluded that the harmonic filtering over the 40th order is compulsory.

The phasor diagram corresponding to the cutoff harmonic order of 40 is depicted by Fig. 13. It reveals a slight unbalance (different phase shifts of voltage-current phase quantities).

TABLE III.
POWER QUALITY INDICES FOR THE AUXILIARY FILTERED OUTPUT VOLTAGES

Power quality index	Cutoff harmonic order		
	80	70	40
$U1_d$ [V]	36.43	32.34	20.91
$U2_d$ [V]	47.81	42.48	24.67
$U3_d$ [V]	45.17	41.94	23.37
$THDU_1$ [%]	12.39	11.02	6.7
$THDU_2$ [%]	15.29	13.62	7.9
$THDU_3$ [%]	15.01	13.96	7.78
S [VA]	36179.87	36110.5	35962.24
P [W]	33716.056	33718.52	33718.32
Q [VAr]	11998.11	11998.02	12006.65
D [VAd]	5203.59	4679.62	3334.64
PF	0.93	0.934	0.94

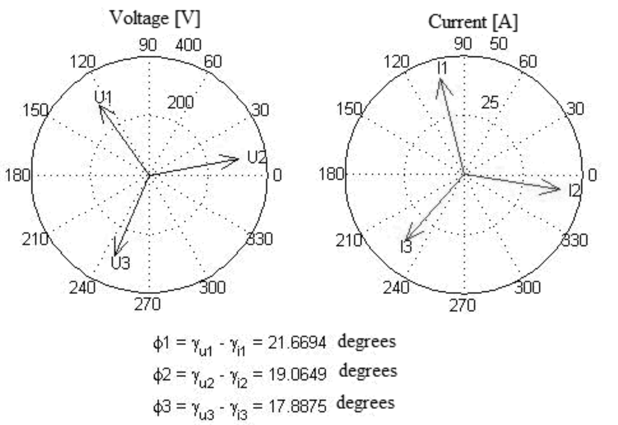


Fig. 13. Phasor diagram for the filtered output voltages with a cutoff frequency corresponding to the 40-th harmonic.

All data from Table 3 reveal that the 2-nd and 3-rd phase voltages contain more significant harmonic contents. The phasor diagrams are not affected by the filtering process.

CONCLUSIONS

This study was focused on operational characteristics of an auxiliary converter used in railway applications which was designed, realized and tested on stand.

Considering the high level of the electromagnetic noise from the environment in which the converter is expected to operate, data representing electrical waveforms acquired from key test points were analyzed with original software packages.

The highest harmonic orders (exceeding the 70-th rank) had to be removed and evaluated in order to reveal the significant low harmonic order components. The instantaneous values representing the pollution with harmonic orders revealed highly variable levels of noise.

Whilst the high orders harmonics removal yielded almost sinusoidal currents, the phase voltages were proved to preserve a significant content of harmonic distortions after the removal of harmonics higher than 70.

The analysis based on the Fast Fourier Transform yielded the most significant power quality indices for cut-off frequencies corresponding to harmonics from the set {40, 70 and 80}.

The harmonic spectra of phase voltages revealed that the weights of most of the harmonic orders overcome the threshold of 1%.

Filtering of all frequencies over the 40-th harmonic was revealed to be a good solution to provide the electromagnetic compatibility.

ACKNOWLEDGMENT

Source of research funding in this article: This work was supported by the grant POCU380/6/13/123990, co-financed by the European Social Fund within the Sectorial Operational Program Human Capital 2014 – 2020.

Contribution of authors:
First author – 30%
First coauthor – 30%
Second coauthor – 20%
Third coauthor – 20%

Received on July 17,2019
Editorial Approval on November 15, 2019

REFERENCES

[1] M. Šuňal, J. Ilončiak and J. Bednár, "Smart converters implemented into auxiliary converter of public transport vehicles," Proceedings of EDPE 2015, Tatranska Lomnica, 2015, pp. 413-416.

[2] M. Ocklenburg, M. Döhmen, X. Wu and M. Helsper, "Next generation dc-dc converters for Auxiliary Power Supplies with SiC MOSFETs," Proceedings of ESARS-ITEC 2018, Nottingham, 2018, pp. 1-6

[3] F. Alkayal and J. B. Saada, "Compact three phase inverter in Silicon Carbide technology for auxiliary converter used in railway applications," Proceedings of EPE 2013, Lille, 2013, pp. 1-10.

[4] S. V. Khuktikov, V. I. Meleshin and A. A. Tochenov, "A novel auxiliary power converter for railway application," Proceedings of PEMC 2014, Antalya, 2014, pp. 211-217.

[5] M. Helsper and M. Ocklenburg, "SiC MOSFET Based Auxiliary Power Supply for Rail Vehicles," 2018 20th European Conference on Power Electronics and Applications (EPE'18 ECCE Europe), Riga, 2018, pp. P.1-P.8.

[6] C. Martinez, A. Lazaro, C. Lucena, I. Quesada, P. Zumel and A. Barrado, "Improved modulator for losses reduction in auxiliary railway power supplies," Proceedings of APEC 2013, Long Beach, CA, 2013, pp. 2324-2331.

[7] M. Porzio et al., "Modern soft-switching topology for galvanic insulated railways auxiliary converter," Proceedings of International Symposium on Power Electronics, Electrical Drives, Automation and Motion, Sorrento, 2012, pp. 861-864.

[8] O. Deblecker, A. Moretti and F. Vallee, "Comparative Study of Soft-Switched Isolated dc-dc Converters for Auxiliary Railway Supply," in IEEE Transactions on Power Electronics, vol. 23, no. 5, pp. 2218-2229, Sept. 2008.

[9] Shuichang, Zhang & , Yun & , Sun & , Peng. (2019). Simulation Research on Auxiliary Power Supply System of China Standard EMU. Electronics

[10] O. Deblecker, A. Moretti and F. Vallee, "Comparative analysis of two zero-current switching isolated dc-dc converters for auxiliary railway supply," Proceedings of International Symposium on Power Electronics, Electrical Drives, Automation and Motion, Ischia, 2008, pp. 1186-1193.

[11] T. Mishima and Y. Koji, "Zero Voltage Soft-Switching Phase-Shift PWM Controlled Three-Level dc-dc Converter for Railway Auxiliary Electric Power Unit," Proceedings of APEC 2019, Anaheim, CA, USA, 2019, pp. 1716-1721.

[12] A. A. Gannshin, V. I. Meleshin, S. A. Sachkov and D. V. Zhiklenkov, "Railway auxiliary power converter operating with 3 kV dc supply line on the basis of 6.5 kV IGBT modules," Proceedings of PEMC 2014, Antalya, Sept. 2014, pp. 654-660.

[13] http://www.vig-info.ro/

[14] http://cesiautomation.ro/

[15] R.F. Marinescu, P.M. Nicolae, A. Hurezeanu and D.C. Marinescu, "Design, Simulations and Manufacturing of an Auxiliary Converter Used in Railway Applications", Proceedings of SIELMEN 2019, Chişinău, October 2019.

[16] Nicolae, I.D., Qays, A., Nicolae, P.M. & Marinescu, R. Complex Power Quality Analysis of Electric Waveforms Affected by Noise. Proceedings of MPS 2019, Cluj Napoca, Romania, May, 2019.

[17] I. Nicolae and P. Nicolae, "Denoising highly distorted small currents in an environment with variable levels of noise," 2017 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMCSI), Washington, DC, 2017, pp. 299-304.