

GALVANIC COUPLING - EMC OF ELECTRICAL SYSTEMS (PART IV.)

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Abstract This paper deals with an analysis of the electromagnetic compatibility (EMC) – galvanic coupling problems focused on the area of power electrical systems. The description of galvanic coupling problem is divided into the separate parts according to the length of common conductors or working frequency. The fourth part (PART IV.) of the work analyses a problem of circuits with distributed parameters, which have several conductors or process high frequency signals. We have used a mathematical analysis, computer simulation method and verification of measurements for detailed investigation of this area.

Key words: electromagnetic compatibility, galvanic coupling, common conductors, long lines.

1. Introduction

Importance of electromagnetic compatibility (EMC) of all electrical products has been rapidly growing during the last decade [1], [2], [3], [4], [5], [6]. The living environment is increasingly polluted by electromagnetic energy. The interference impact on the surroundings is being doubled every three years and covers a large frequency range [7], [8], [9], [10]. Equipment disturbances and errors have become more serious as a consequence of the growth of the electronic circuit complexity [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21]. According to a new technical legislation and also due to economic consequences, the EMC concept of all products must be strictly observed [22], [23], [24]. It must start with the specification of the equipment performance and end with the equipment installation procedures.

We use computer simulation to investigate EMC of electrical products with different types and difficulty levels instead of time-consuming theoretical analysis or costly experiments [25], [26].

The contribution of this paper consists of derivation of relations valid for non-harmonic inverter's output voltage connected to the load by three-phase cable. The solution for the higher frequencies and distributed parameters are presented in the following chapter 2. The theoretical analysis

is discussed in subchapter 2.1. The simulation and measuring of parameters are demonstrated in subchapter 2.2. The last chapter 3 consists of the conclusions.

2. Solution for the Higher Frequencies and Distributed Parameters

The working frequencies and the length of common conductors must be always taken into the account. In all cases of the galvanic coupling, the fact that electrical components are not ideal and so they are containing certain parasitic capacitances, inductances and real resistances, is valid. Due to existence of the contents of higher harmonics in currents that flow across the common conductors, such circuits must be taken as circuits with distributed parameters during the process of predictive result galvanic coupling investigation. If the working frequencies will be lower, then the interconnecting circuits can be taken as circuits with concentrated parameters.

2.1. Theoretical analysis - several conductors

In the practical exploitation of power semiconductor converters a very often case occurs when symmetric three-phase load is connected to the inverter impulse output with the frequency of few tenths of kHz by the cable that is 3 to 20 m long. Such topology represents the three-phase interconnection of two circuits by a long line with the distributed parameters, as is shown on Fig. 1.

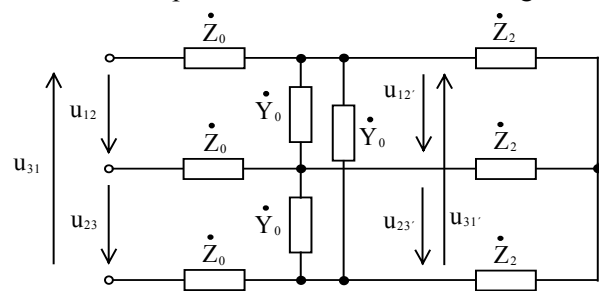


Fig. 1. The circuit interconnection by cable line with distributed parameters

The investigation of galvanic coupling of such circuit can be done by calculation of the output voltages u_{12}' , u_{23}' and u_{31}' at the end of a long transmission line. The input voltages are graphically shown on Fig. 2.

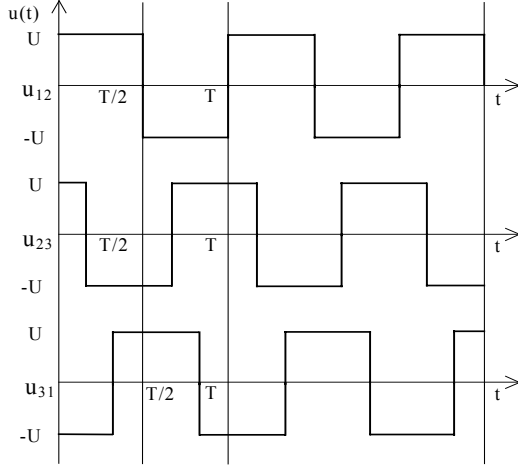


Fig. 2. The input voltages u_{12} , u_{23} and u_{31}

The amplitudes of the input voltages are $U = 400$ V. The interconnecting cable with the parameters was used: CYSY 4x1,5 mm², with the length 15m, $R_0 = 0,047$ Ω /m, $L_0 = 343$ nH/m, $G_0 = 33,3$ μ S/m, $C_0 = 118$ pF/m. The load is symmetric with parameters: $R_2 = 10$ Ω , $L_2 = 1$ mH. To calculate the output voltages u_{12}' , u_{23}' and u_{31}' the equations derived from previous analyses [27], [28] can be used. However, the feeding of non-harmonic input voltages is necessary to express using harmonic functions. The Fourier's series [29] will be used again.

$$a_0 = \frac{1}{T} \int_0^{T/2} U \cdot dt + \frac{1}{T} \int_{T/2}^T -U \cdot dt = 0 \quad (1)$$

$$a_k = \frac{2}{T} \int_0^{T/2} U \cdot \cos(k\omega t) dt + \frac{2}{T} \int_{T/2}^T -U \cdot \cos(k\omega t) dt = \frac{U}{k\pi} ((\sin(k\pi) - \sin(0)) - (\sin(k2\pi) - \sin(k\pi))) = 0 \quad (2)$$

$$b_k = \frac{2}{T} \int_0^{T/2} U \cdot \sin(k\omega t) dt + \frac{2}{T} \int_{T/2}^T -U \cdot \sin(k\omega t) dt = -\frac{U}{k\pi} ((\cos(k\pi) - \cos(0)) - (\cos(k2\pi) - \cos(k\pi))) = \frac{4U}{(2k+1)\pi} \quad (3)$$

$$u_{12}(t) = \frac{4U}{\pi} \sin(\omega t) + \frac{4U}{3\pi} \sin(3\omega t) + \frac{4U}{5\pi} \sin(5\omega t) + \dots = \sum_{k=0}^{\infty} \frac{4U}{(2k+1)\pi} \sin((2k+1)\omega t) \quad (4)$$

The other two voltages are expressed consequently with regard on the translation in time.

$$u_{23}(t) = \frac{4U}{\pi} \sin(\omega(t - \frac{T}{3})) + \frac{4U}{3\pi} \sin(3\omega(t - \frac{T}{3})) + \frac{4U}{5\pi} \sin(5\omega(t - \frac{T}{3})) + \dots = \sum_{k=0}^{\infty} \frac{4U}{(2k+1)\pi} \sin((2k+1)\omega(t - \frac{T}{3})) \quad (5)$$

$$u_{31}(t) = \frac{4U}{\pi} \sin(\omega(t - \frac{2T}{3})) + \frac{4U}{3\pi} \sin(3\omega(t - \frac{2T}{3})) + \frac{4U}{5\pi} \sin(5\omega(t - \frac{2T}{3})) + \dots = \sum_{k=0}^{\infty} \frac{4U}{(2k+1)\pi} \sin((2k+1)\omega(t - \frac{2T}{3})) \quad (6)$$

If the expressions calculated for the input voltages are substituted by the equation (19) derived in part I. [27], which describes the temporal dependence of the voltage at the end of the cable line, thus we can obtain the relations (7) till (9). The condition is that only the imaginary part of the complex solution will be taken into the account, because only this part corresponds to the sinusoidal input voltage.

During the calculation process, the recalculation of load impedance value (from star to triangle) must be performed, because the temporal curves of interline voltages are being searched. The MS Excel program will be used to obtain the graphical representation of the achieved results. It shows graphical results containing the first 40 components of Fourier's series. The respective curves are drawn in Fig. 3. to Fig. 10.

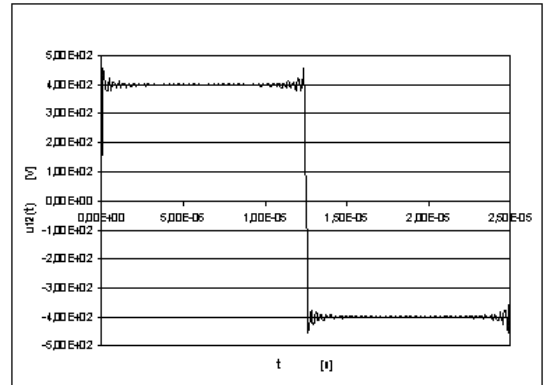


Fig. 3. Synthesis of the input voltage u_{12}

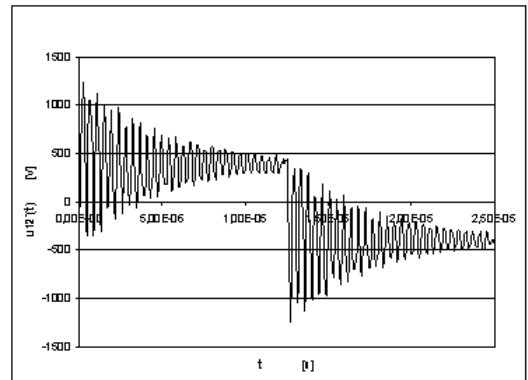


Fig. 4. The output voltage u_{12}'

$$u_{12}(t) = \sum_{k=0}^{\infty} \frac{2U}{(2k+1)\pi} \cdot (e^{\beta l} \cdot \sin((2k+1)\omega t + \varphi_U + \alpha l) + e^{-\beta l} \cdot \sin((2k+1)\omega t + \varphi_U - \alpha l) - \frac{\sqrt{a^2 + b^2}}{\sqrt{c^2 + d^2}} \cdot e^{\beta l} \cdot \sin((2k+1)\omega t + \varphi_U + \alpha l + \arctg \frac{b}{a} - \arctg \frac{d}{c}) + \frac{\sqrt{a^2 + b^2}}{\sqrt{c^2 + d^2}} \cdot e^{-\beta l} \cdot \sin((2k+1)\omega t + \varphi_U - \alpha l + \arctg \frac{b}{a} - \arctg \frac{d}{c})) \quad (7)$$

$$u_{23}(t) = \sum_{k=0}^{\infty} \frac{2U}{(2k+1)\pi} \cdot (e^{\beta l} \cdot \sin((2k+1)\omega(t - \frac{T}{3}) + \varphi_U + \alpha l) + e^{-\beta l} \cdot \sin((2k+1)\omega(t - \frac{T}{3}) + \varphi_U - \alpha l) - \frac{\sqrt{a^2 + b^2}}{\sqrt{c^2 + d^2}} \cdot e^{\beta l} \cdot \sin((2k+1)\omega(t - \frac{T}{3}) + \varphi_U + \alpha l + \arctg \frac{b}{a} - \arctg \frac{d}{c}) + \frac{\sqrt{a^2 + b^2}}{\sqrt{c^2 + d^2}} \cdot e^{-\beta l} \cdot \sin((2k+1)\omega(t - \frac{T}{3}) + \varphi_U - \alpha l + \arctg \frac{b}{a} - \arctg \frac{d}{c})) \quad (8)$$

$$u_{31}(t) = \sum_{k=0}^{\infty} \frac{2U}{(2k+1)\pi} \cdot (e^{\beta l} \cdot \sin((2k+1)\omega(t - \frac{2T}{3}) + \varphi_U + \alpha l) + e^{-\beta l} \cdot \sin((2k+1)\omega(t - \frac{2T}{3}) + \varphi_U - \alpha l) - \frac{\sqrt{a^2 + b^2}}{\sqrt{c^2 + d^2}} \cdot e^{\beta l} \cdot \sin((2k+1)\omega(t - \frac{2T}{3}) + \varphi_U + \alpha l + \arctg \frac{b}{a} - \arctg \frac{d}{c}) + \frac{\sqrt{a^2 + b^2}}{\sqrt{c^2 + d^2}} \cdot e^{-\beta l} \cdot \sin((2k+1)\omega(t - \frac{2T}{3}) + \varphi_U - \alpha l + \arctg \frac{b}{a} - \arctg \frac{d}{c})) \quad (9)$$

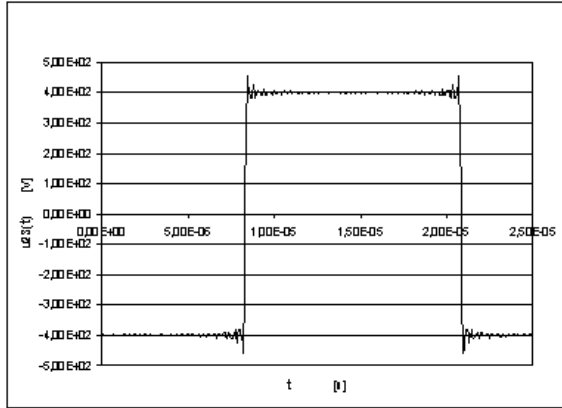


Fig. 5. Synthesis of the input voltage u_{23}

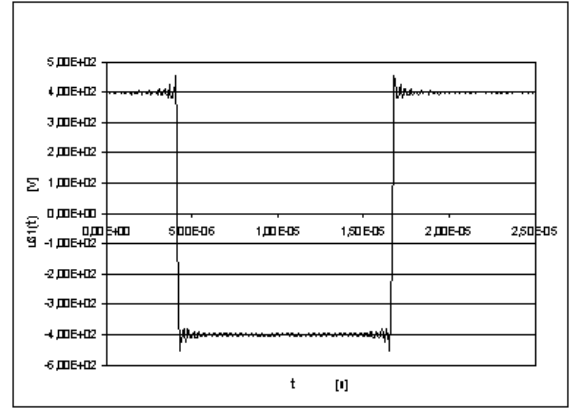


Fig. 7. Synthesis of the input voltage u_{31}

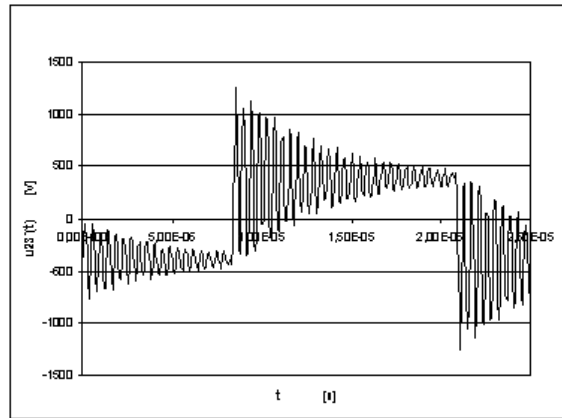


Fig. 6. The output voltage u_{23}'

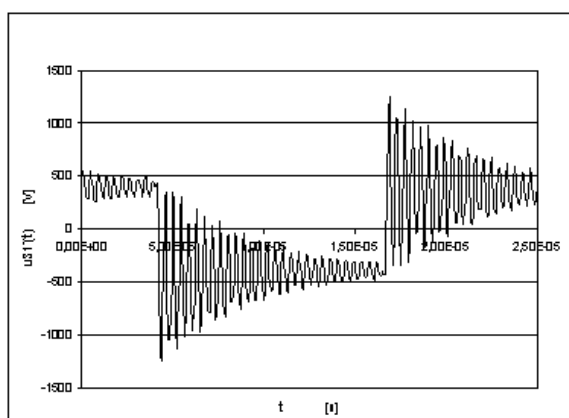


Fig. 8. The output voltage u_{31}'

The following two figures show the sum of all three input and output voltages. From the shape of the graphs, it is evident, that during such a choice of the feeding signal shape, the non-harmonic supply system, containing the expressive amount of 3rd harmonic voltage and its multiples, is generated.

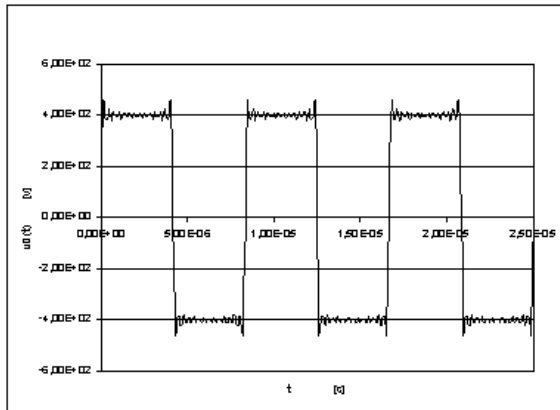


Fig. 9. The potential of the inverter neutral node

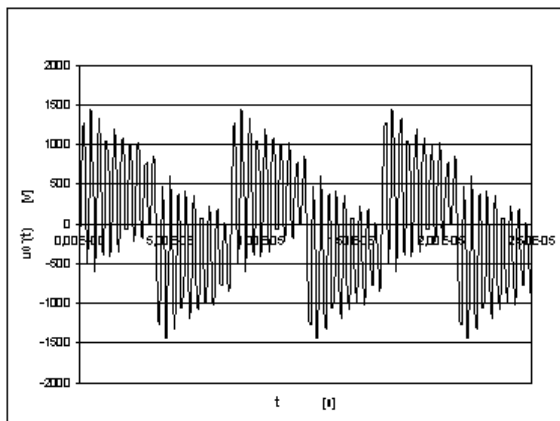


Fig. 10. The potential of the load node

As result of the existence of nodal potential difference the loop current, flowing via neutral wire, can be generated in the case of four-conductor circuit interconnection. However, such situation is in the contradiction to the standard requirements.

2.2. Simulation and Measuring - Several conductors

For the subsidiary verification of simulations, the MS Excel program can be utilized again. The long transmission line (cable) with the distributed parameters will be replaced by a line with concentrated parameters corresponding to its length. The simulation results are displayed in the following two figures Fig. 11. and Fig. 12.

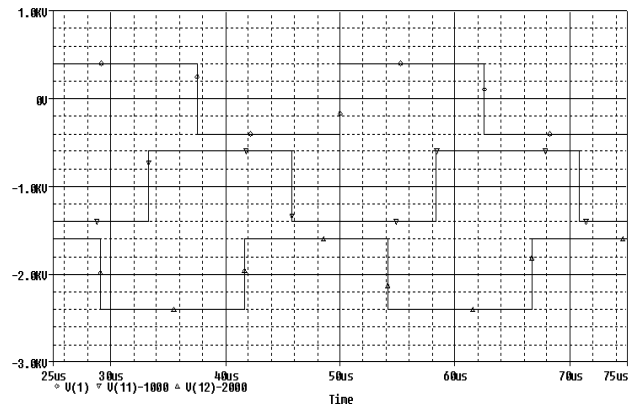


Fig. 11. The three-phase input non-harmonic voltage system obtained by simulation

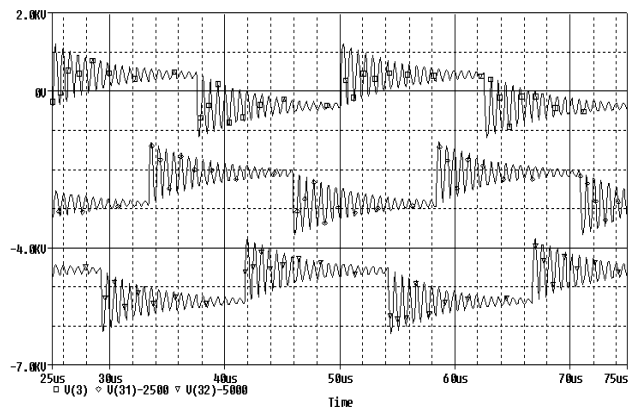


Fig. 12. The output voltages of the three-phase load system obtained by simulation

The coincidence between the curves obtained by analytical calculation and by the computer simulation method is evident. So we can suppose that the derived relations are correct. The verified measurement results are shown in the figures Fig. 13. to Fig. 18.

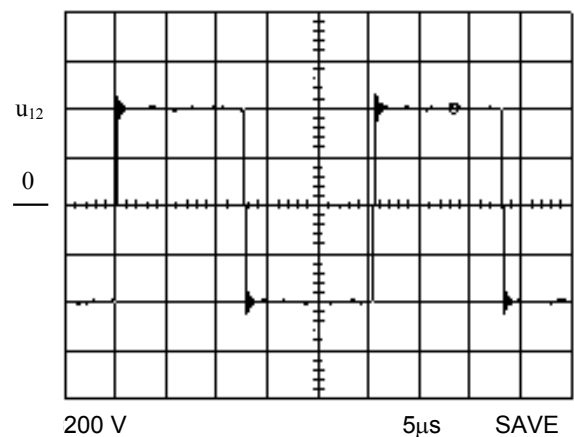


Fig. 13. The input voltage u_{12}

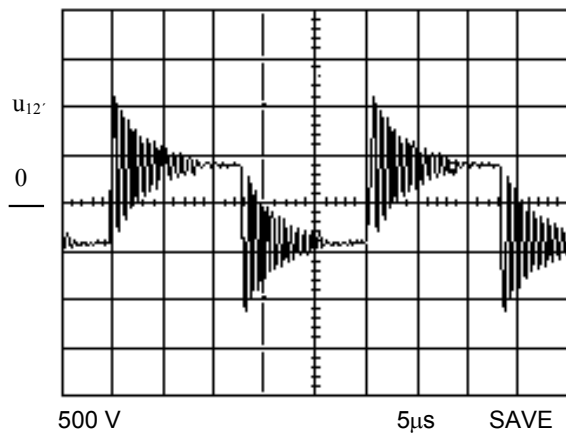


Fig. 14. The output voltage $u_{12'}$

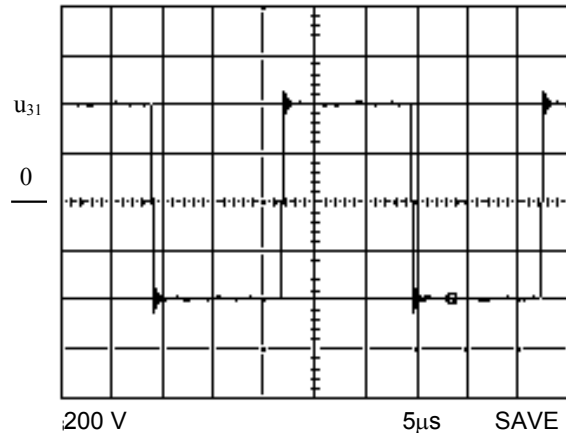


Fig. 17. The input voltage u_{31}

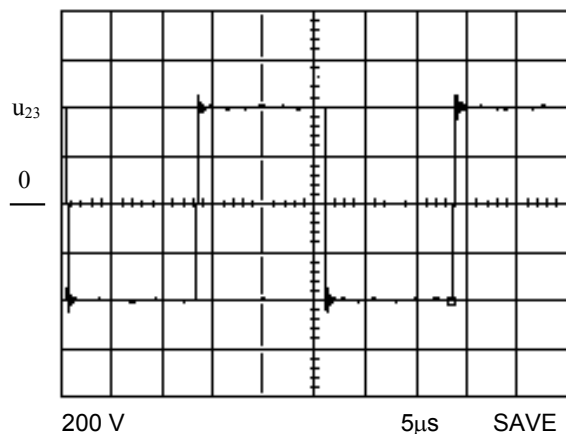


Fig. 15. The input voltage u_{23}

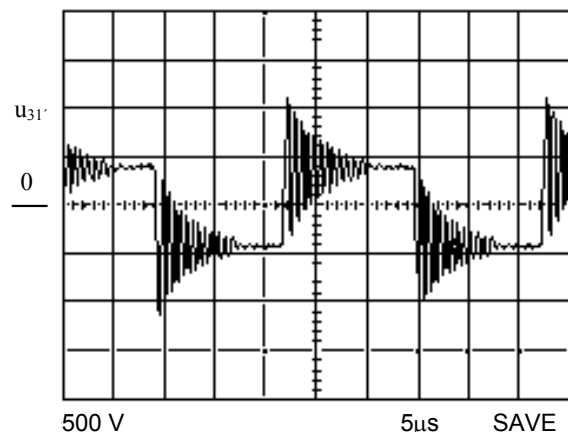


Fig. 18. The output voltage $u_{31'}$

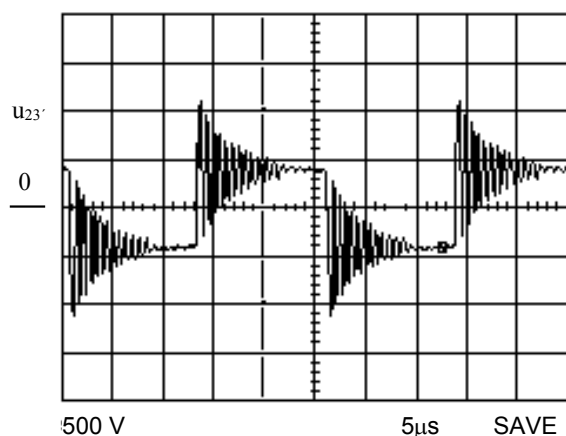


Fig. 16. The output voltage $u_{23'}$

3. Conclusion

The performed analysis discovers the fact that parameters of the cable that interconnects inverter and the load can have important influence on its working conditions and so also on its EMC. It also points on the existence of different potentials

between the three-phase inverter neutral node and three-phase load node with the great value of the 3rd harmonics. The accuracy of all obtained results was confirmed by computer simulation and by measurements. Its mutual coincidence is evident.

Derived equations enable to solve the described problem by numerical computing and computer simulation very easily. In this way it is possible to design the correct load and load filters. So it gives opportunities to improve the EMC parameters of the newly constructed devices not only by expensive testing measurements, but also using theoretical analysis and simulation tools. Based on the results introduced in this paper, the constructors can determine the EMC properties of the devices by a predictive method. Then the EMC improvement will thus be more comfortable, cheaper, easier and faster.

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References

1. Carpenter, D. J.: *EMC Emissions Certification for Large Systems – A Risk – Management Approach*. BT Technology Journal, Springer Science + Business Media B. V. Vol. 21, 2003, No. 2, pp. 67-76.
2. Kováčová, I., Kováč, D., Kaňuch, J.: *EMC from the look of the theory and applications*. BEN – technical literature Publisher, Prague 2006, 220 pages, ISBN 80-7300-202-7.
3. Kováč, D., Kováčová, I.: *Influence of Utilizing Static Power Semiconductor Converters on Quality of Electrical Power Line Parameters*. Quality Innovation Prosperity, No.1, 2001, pp. 74-84.
4. Ming-Dou, K., Tai-Hsiang, L.: *Investigation on Robustness of CMOS Devices Against Cable Discharge Event (CDE) Under Different Layout Parameters in a Deep-Submicrometer CMOS Technology*. IEEE Transactions on Electromagnetic Compatibility, Vol. 50 (2008), No. 4., pp. 810-821.
5. Degardin, V., Lienard, M., Degauque, P., Simon, E., Laly, P.: *Impulsive Noise Characterization of In-Vehicle Power Line*. IEEE Transactions on Electromagnetic Compatibility, Vol. 50 (2008), No. 4., pp. 861-868.
6. Gursoy, M., Jahn, S., Deutschmann, B., Pelz, G.: *Methodology to Predict EME Effects in CAN Bus Systems Using VHDL-AMS*. IEEE Transactions on Electromagnetic Compatibility, Vol. 50 (2008), No. 4., pp. 993-1002.
7. Agelidis, V. G., Balouktsis, A., Balouktsis, I.: *On applying a minimization technique to the harmonic elimination PWM control: the bipolar waveform*. IEEE Power Electronics Letters, Vol. 2 (2004), No. 2., pp. 41-44.
8. Gubia, E., Sanchis, P., Ursua, A., Lopez, J., Marroyo, L.: *Frequency domain model of conducted EMI in electrical drives*. IEEE Power Electronics Letters, Vol. 3 (2005), No. 2., pp. 45-49.
9. Ozpineci, B., Tolbert, L. M., Chiasson, J. N.: *Harmonic optimization of multilevel converters using genetic algorithms*. IEEE Power Electronics Letters, Vol. 3 (2005), No. 3., pp. 92-95.
10. Bučko, R., Tomčíková, I.: *Vapor Phase Soldering*. 10th International PhD Workshop OWD 2008, Warszawa, Komitet badania naukowe, 2008, pp. 603-606.
11. Tomčík, J., Tomčíková, I.: *Safety policy of automation and SCADA systems*. Journal of Electrical Engineering and Energetics Vol. 14, No. 1., 2008, pp. 9-11.
12. Kűs, V.: *The influence of power semiconductor converters on power distribution net*. BEN – technical literature Publisher, Prague 2002, 184 pages, ISBN 80-7300-062-8.
13. Kováčová, I., Kováč, D.: *EMC Compatibility of Power Semiconductor Converters and Inverters*. Acta Electrotechnica et Informatica, No.2, Vol. 3, 2003, pp. 12-14.
14. Mihet - Popa, L., Boldea, I.: *Control strategies for large wind turbine applications*. Journal of Electrical Engineering, Romania, Vol. 7, No. 3, 2007.
15. Di Rienzo, L., Yuferev, S., Ida, N.: *Computation of the Impedance Matrix of Multiconductor Transmission Lines Using High-Order Surface Impedance Boundary Conditions*. IEEE Transactions on Electromagnetic Compatibility, Vol. 50 (2008), No. 4., pp. 974-984.
16. Levin, B. M.: *Calculation of Electrical Parameters of Two-Wire Lines in Multiconductor Cables*. IEEE Transactions on Electromagnetic Compatibility, Vol. 50 (2008), No. 3., Part 2., pp. 697-703.
17. Busquets-Monge, S., Bordonau, J., Boroyevich, D., Somavilla, S.: *The nearest three virtual space vector PWM - a modulation for the comprehensive neutral-point balancing in the three-level NPC inverter*. IEEE Power Electronics Letters, Vol. 2 (2004), No. 1., pp. 11-15.
18. Vince, T., Molnár, J., Tomčíková, I.: *Remote DC Motor Speed Regulation via Internet*. 10th International PhD Workshop OWD 2008, Warszawa, pp. 293-296, 2008.
19. Vince, T., Kováčová, I.: *Distance control of mechatronic systems via Internet*. Acta Electrotechnica et Informatica. Vol. 7, No. 3, 2007, pp. 63-68.
20. Tomčíková, I., Mojžiš, M.: *Elastomagnetic sensor for torque measurement*. Faculty of Electrical Engineering and Informatics, Research and Development Projects, Košice, Elfa, 200, pp. 99-100.
21. Tomčíková, I., Molnár, J., Vince, T.: *Interaction of magnetic field and tenseness for elastomagnetic sensor of pressure force*. Elektrotechnika. No. 34, 2008, pp. 34-1-34-11.
22. Molnár, J., Kováčová, I.: *Distance remote measurement of magnetic field*. Acta Electrotechnica et Informatica, Vol. 7, No. 4, 2007, pp. 52-55.
23. Göksu, H., Wunsh, D. C.: *Neural Networks Applied to Electromagnetic Compatibility Simulations*. Lecture Notes in Computer Science, Springer - Verlag GmbH, Vol. 2714, 2003, pp. 1057-1063.
24. Kováčová, I., Kováč, D., Kaňuch, J., Gallová, Š.: *EMC of Electrical Drives Part VII*. AT&P Journal, 2006, No.8, pp. 53-54.
25. Kováčová, I., Kováč, D., Kaňuch, J., Gallová, Š.: *EMC of Electrical Drives Part VI*. AT&P Journal, 2006, No.7, pp. 85-87.
26. Orendáč, M., Tomčíková, I.: *Basics of Electrical Engineering. Lectures and exercises*. Košice, Elfa, 2005, 132 pages, ISBN 80-8086-013-0.
27. Kováčová, I., Kováč, D.: *Galvanic Coupling - EMC of Electrical Drives (Part I)*. Journal of Electrical Engineering, Romania, Vol. 6, No. 2, 2006, pp. 15-23.
28. Kováč, D., Kováčová, I.: *Galvanic Coupling - EMC of Electrical Systems (Part III)*. Journal of Electrical Engineering, Romania, Vol. 8, No. 2, 2008, pp. 141-144.
29. Tomčíková, I.: *Selected chapters from Electrical Engineering I*. Košice, Elfa, 148 pages, 2005, ISBN 80-8086-017-3.