On-line measurements of input impedance of an electric traction vehicle supplied by DC catenary for identification and reduction of disturbances in signalling and control track circuits

Marcin Steczek[1], Adam Szeląg[2]

[1] *Łódź University of Technology, Stefanowskiego St., 90-924 Łódź, marcin.steczek@p.lodz.pl*
[2] *Warsaw University of Technology, Pl. Politechniki 1, 00-661 Warsaw, adam.szelag@ee.pw.edu.pl*

Abstract- The use of power electronics in modern drive systems that are used for traction purposes, makes it necessary to conduct EMC control regarding disturbances in operation of other devices of railway infrastructure that are caused by the vehicles, especially in traffic and signalling management systems. One of the investigated parameters is the value of input impedance of a vehicle. The article presents the results of works on analysis of traction vehicles input impedance as well as impedance measurements under laboratory conditions. The possibility of on-line measurements of impedance in vehicles operating conditions was discussed, the use of these results in a diagnostics system measuring the level of disturbances from higher harmonics introduced by a vehicle into the rail network were also presented. One proposed application of an algorithm enabling introduction of the changes of the manner of control of a vehicle's drive system, while maintaining the required torque that is developed by the vehicle's motors, but at the lowest level of introduced disturbances.

I. Introduction

The works [1,2,3,4,5,10,12,13,14] on the matters covered by the article show that there are some conditions under which input impedance of a traction drive system is not a constant value that depends only on the parameters of an input filter, but might also undergo changes with the change of an inverter's operating point. Due to this fact, the issue of measuring the traction vehicle input impedance is a current problem, which should be analysed in detail. The essence of the problem is underlined by the standard [17], which defines minimum admissible value of vehicle input impedance, for the frequency of 50 Hz at the level of 0.3 Ω. Furthermore, to reduce occurrence of harmonics of frequencies from the ranges of track circuits operating areas in the vehicle's current, railway authorities are introducing appropriate limitations regarding those harmonics.

The article presents the issues regarding the use of vehicle's input impedance to create a system controlling the possibility of occurrence of higher harmonics disturbances of current consumed from a DC traction network by a traction vehicle that is equipped with a drive with a cage motor supplied from a voltage inverter. It was proposed to determine input impedance of DC supplied traction vehicles drive systems using measurements, with a special measuring technique that employs analysis of registered waveforms of current and voltage at the input of the system under analysis. For this purpose, a measurement application in the LabView programme, which cooperates with a check chart was developed and verified. This application allows determining both a module and impedance argument of drive systems equipped with asynchronous motors supplied with inverters and DC motors equipped with choppers. The application was verified based on comparison of results of laboratory measurements with the results of computer simulation. Then, one proposed a concept of a system for on-line control of input impedance values of a traction vehicle with a system of further processing of the measured signals and an algorithm of the change of control of an inverter supplying a cage motor so as to maintain the operating point of a vehicle's drive (power, torque, speed) with maintenance of disturbances level (current higher harmonics) at the admissible level [3,4,5,7,8,9,15,16,18,19].

II Input impedance of traction electric vehicles determined based on computer simulation

The typical solutions of drive systems used in traction vehicles that use static converters of high power are: DC motor supplied with use of a chopper and asynchronous motors with use of an inverter.

Fig. 2 presents exemplary results of simulation determination of input impedance of a vehicle with DC motors for the frequency of 50 Hz, which is equipped with 3 types of filters (impedance module in the function of a duty cycle k) [7,12]. Fig. 1 presents results of the simulation determination of input impedance of a vehicle equipped with asynchronous motors supplied with voltage inverters (impedance module in a function of frequency of basic component of output voltage of an inverter). Simulation was conducted assuming various control strategies. As it was previously mentioned, the presented results indicate the possibility of occurrence of such conditions, in which input impedance of a traction vehicle is not a constant parameter, and instead it changes with the change of the converter operating point.
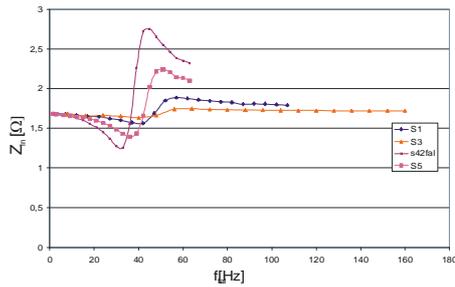
Figure 1. Traction drive system input impedance module (Z_{in}) versus frequency (f_{fal}) for input filter F2
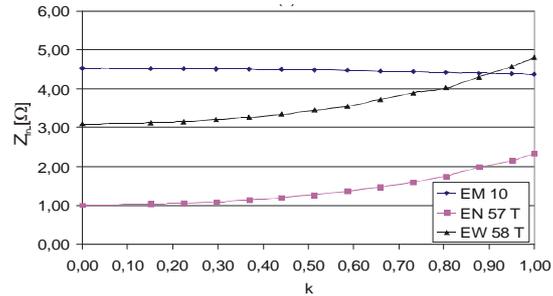
Figure 2. Variation of the 50 Hz input impedance with different filters versus chopper cycle period ratio k

III Measurement system

For measurements a specialized measuring system was derived and verified. The input impedance is calculated by processing signals u1 and u2 in designed application (Fig. 3). The application has been designed with LabVIEW software thanks to its advanced processing capabilities, uncomplicated cooperation with a measuring card and stable real time performance. Voltage u_1 is measured on power supply pins, voltage u_2 is taken from R_{pom} resistor. Measurement of voltage u_2 is for indirect circuit current measurement. The program algorithm calculates the current where the voltage u_2 is divided by value R_{pom}. Optionally measuring transducers can be used. Both signals are delivered to two different measuring card channels with 50 kHz probing frequency for each channel. Processing is carried out at 10 V measuring range.
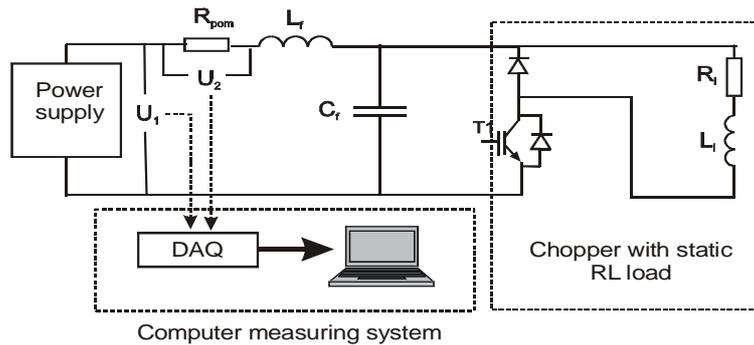

Figure 3. A block diagram of the measuring system for measurements of an impulsive chopper with a static RL load
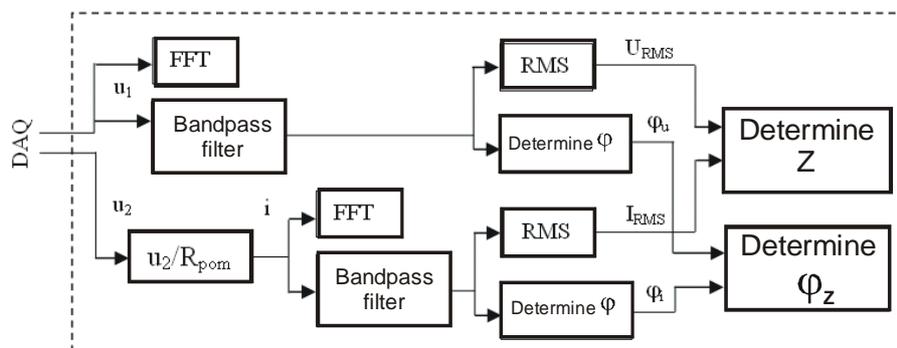

Figure 4. A block diagram of the algorithm for the impedance measurement

Figure 4 presents block diagram of the implemented algorithm. Voltage signal from resistor R_{pom} is divided by its value to acquire a digital signal (value of the current). Next, both channel 1 (supply voltage) and channel 2 (current) signals are processed equally in parallel DFT algorithms and filtered. DFT analysis allows for signal harmonics identification and filtration of the proper harmonics. The results of DFT are displayed at proper

graphs in a user interface panel. The band-pass filtration is carried out by band-pass filters with infinite pulse response (NOI) 6TH grade. To measure 50 Hz input impedance low frequency should be fixed at 45 Hz and high frequency should be fixed at 55 Hz. The additional function of band-pass filters is to eliminate any disturbances during the measurement. Because of the unsteady state affected by the filter only the 2nd half (samples taken during one second of the measurement) of the taken samples is processed during further calculations. The taken signals are processed into current and voltage RMS values. To eliminate all unpredictable disturbances RMS values are calculated from 200 time periods for each processed signal.(for example 50 Hz signal frequency). The main disadvantage of this approach is the inevitability of the analysed frequency voltage harmonic occurrence in feeding voltage. As an alternative, other methods of signal spectrum analysis as ESPRIT [3] may be applied.

All significant calculated values are displayed at the user interface panel**.** Moreover, interface allows for R_{pom} value, band-pass filters parameters, measurement time, probing frequency and measuring card parameters to be fixed. At three different parts of the users panel the current and voltage harmonic spectra and waveforms are shown.

IV Results of the laboratory measurements of input impedance of a drive system with a DC motor

Measurements of the input impedance of a series DC motor supplied from an impulse were conducted in a system presented in Fig. 5. Impedance was determined based on the registered waveforms $I_{in}(t)$ and $U_{in}(t)$, which allowed for determination of impedance seen at terminals A-B (Fig. 5). The source of a voltage harmonic necessary for measuring the impedance by a chosen method was a half-wave rectifier.
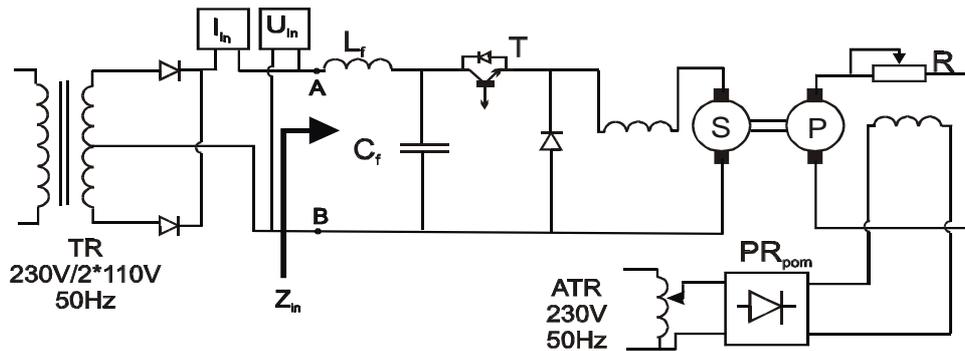

Figure 5. Laboratory scheme for measurement of input impedance of a drive system with a DC motor supplied by a chopper

The measurements were conducted at various characteristics of the load (OBC) stemming from the characteristic of the separately excited generator P. Results of the measurements at changeable parameters are in Fig. 6.
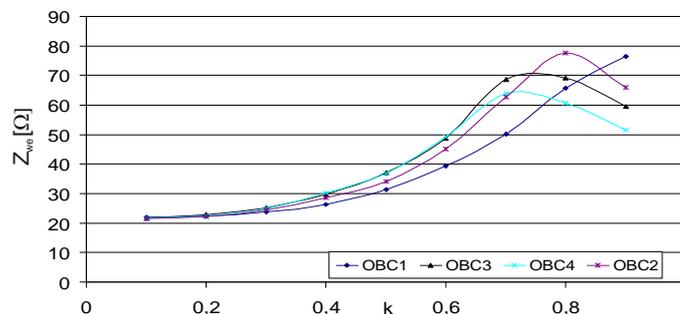

Figure. 6 Impedance module (for f = 100 Hz) of an impulse drive system measured under laboratory conditions - filter capacity $C_f = 50$ μF, impulse frequency $f_{cz} = 300$ Hz

V Results of the laboratory measurements of input impedance of a drive system with an asynchronous motor

The above-described method was used to measure input impedance of a drive system with an AC motor. One determined a system impedance module Z_{in} between A-B terminals of an input filter (

Fig7). For this particular purpose, one recorded waveforms of current and voltage at the input of a filter (I_{in}, U_{in}). Fig. 8 presents a comparison of the simulation and measurement results.
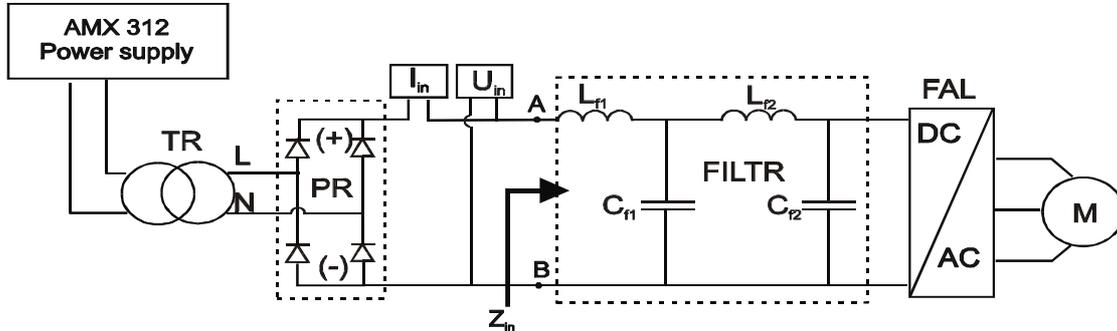

Figure. 7 Scheme of the inverter drive system employed for measurements of input impedance Z_{in} under laboratory conditions
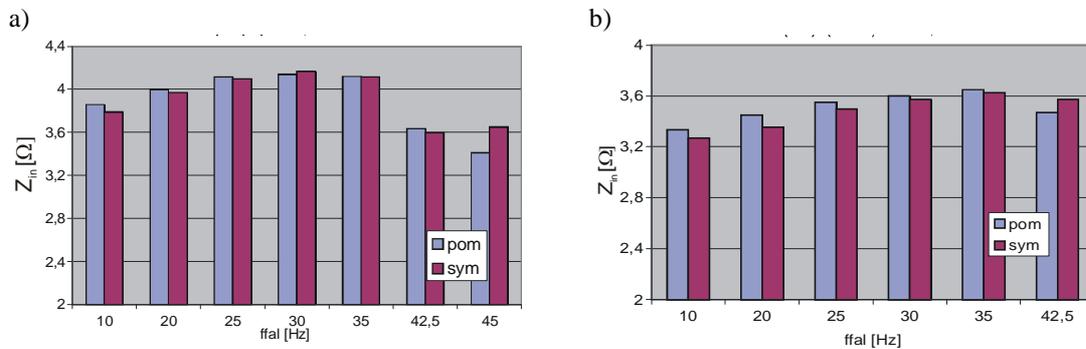
a)

b)

Figure 8. Comparison of the results of impedance determination based on computer simulation with the results of laboratory measurements for various frequencies of converter operation (f_{fal}) with inductance of an input filter $L_{f1} = 1,8mH$ a) impedance for 41 Hz harmonic, b) impedance for 46 Hz

VI The concept of the measurement system for on-line diagnostics of disturbances at a traction vehicle

As it was shown there are conditions in which input impedance of a vehicle (of a drive system) might be a parameter dependent on the operating point of a converter and might reach the required value. Due to this fact it is necessary to conduct simulation studies at the vehicle's prototype stage, which would enable minimization of the probability of occurrence of a similar situation. However, it is not possible to forecast all situations (configurations) that might occur during exploitation of a vehicle. The solution to this problem could be a system monitoring the state of a vehicle in terms of a level of input impedance, which would enable on-line measurements of this parameter and would respond to its lowering by influencing on the control by a drive system.

In the subject matter literature, there are descriptions regarding use of the monitors of fault current of traction vehicles. The use of the results of the measurement and spectral analysis of the on-line time waveform of current, and in case of exceeding the admissible level of disturbances - switching on additional filters or limiting the power of a vehicle. This paper proposes a new concept of a system for identification of possible disturbances and for control of vehicle operation, namely the use of an on-line measurement of input impedance of a traction vehicle in the function of frequency as an additional criterion, furthermore, by use of an appropriate algorithm a feedback of the measurement and control system with a control system using power electronics drive of a traction vehicle in order to change the applied, at the moment of a measurement, operation algorithm so as to provide fulfilment of the requirements regarding no distortions of the traffic control and signalling circuits.
Described system also suits naturally for monitoring of the harmonics consumed by the vehicle from a supply system. The operational scheme of the proposed measurement system is presented in Fig. 9. In control of the operation of a typical drive - an inverter supplying the motor of a vehicle, various methods for attainment of the

set power of a drive are being used. These methods operate based on shaping voltage of a given frequency by PWM of a voltage wave that comes from an inverter [3,4,12]. In case when for a set operating point (vehicle's speed, power), a measurement system identifies on-line, the excess of admissible criteria (input impedance of a vehicle and current harmonics in the function of frequency), the operation algorithm of the proposed system, from the previously prepared table of states of the inverter operation (power, output voltage for a given frequency) will choose such a manner of operation (angles of switch-overs of inverter connectors) so as to decrease content of input current harmonics of frequencies for which limits have been exceeded and for which vehicle's input impedance is below the admissible value. For instance, it may mean, in case of use of the method of elimination of the set harmonics SHE [3,12,16], that transmission from an operation mode without elimination (modulation sin/triangle - SIN/TR) to the elimination of voltage harmonics V_{ph} of the range of 5, 29,31,35,37, allows for attainment of limitation of the maximum value of current harmonics generated by a drive system [I_{fal}] in the range of 1500 - 2000 Hz from 264 to 20 A with maintenance of the same amplitude and frequency of the basic component of output voltage from an inverter. It allows for decrease of minimum admissible attenuation of a filter used in a vehicle, which leads to decrease of the risk of occurrence of disturbing influence of a vehicle on the traffic control system in a selected range of frequency (Fig. 10).
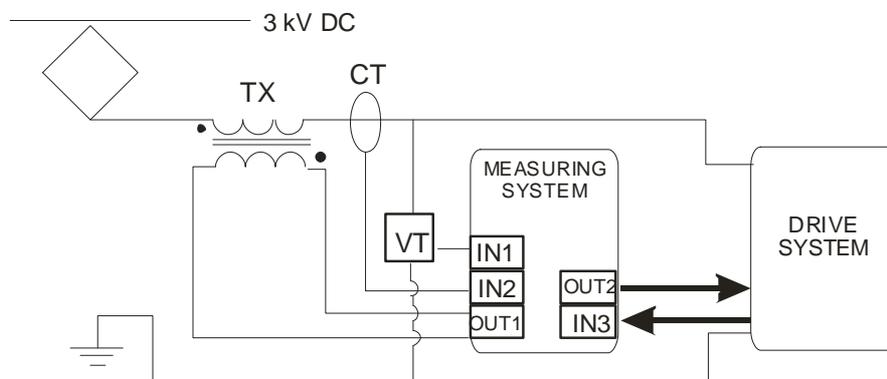

Figure 9. Measuring system concept schema. IN1 - input channel for voltage waveform acquisition, IN2 - input channel for current waveform acquisition, OUT1 - output channel for harmonic injection (essential for input impedance measurement), IN3/OUT3 - input/output channel for drive system and measuring system data transmission, CT – current transducer, VT – voltage transducer, TX – current transformer
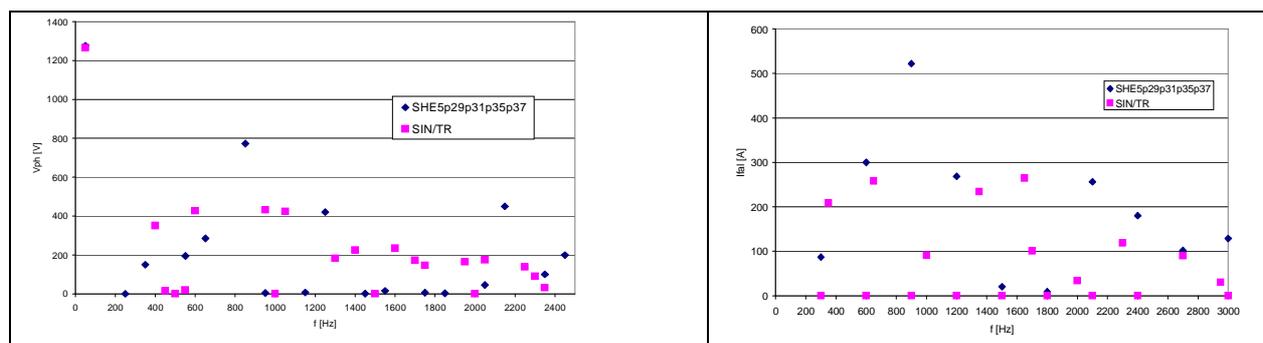

Figure 10. Comparison of the results of simulation determination of the harmonics spectrum with application of elimination and without elimination a) V_{ph} [V] phase voltage of a model of a motor b) I_{fal} [A] current generated by the inverter of a drive system

Conclusions

The article presents the issues regarding the use of vehicle's input impedance to create a system controlling the possibility of occurrence of higher harmonics disturbances of current consumed from a DC traction network by a traction vehicle that is equipped with a drive with a cage motor supplied from a voltage inverter. The application was verified based on comparison of results of laboratory measurements with the results of computer simulation. One proposed determination of input impedance of drive systems of traction vehicles supplied from a DC network and use of the results of these measurements in the system for on-line control of the values of input impedance of a traction vehicle with a system of further processing of the measured

signals and an algorithm of change of control of an inverter supplying a cage motor so as to maintain the operating point of a vehicle's drive (power, torque, speed) with maintenance of disturbances level (current higher harmonics) at the admissible level. The use of such a system will allow for:

− decrease of dimensions of an input filter of a vehicle,

− decrease of the possibility of occurrence of disturbances in the operation of the circuits of the traffic signalling and control system, especially when new vehicles are introduced onto the line with old infrastructure,

− decrease of the situations requiring power reduction (torque), which is developed by a drive of a vehicle in case of the excess of the admissible level of disturbances threatening the appropriate operation of the control and signalling systems (the system will automatically change the manner of drive control while maintaining the point of operation-power, torque, speed with elimination of the harmonics exceeding admissible limits).

References

[1] J. Bongiorno, A. Mariscotti, "Variability of pantograph impedance curves in DC traction systems and comparison with experimental results". *Przegląd Elektrotechniczny*, 6/2014

[2] P. C. Coles, M. Fracchia, R.J. Hill, P. Pozzobon, A. Szeląg, "Identification of catenary resonance conditions on 3 kV DC traction systems. 7th Mediterranean Electrotechnical Conference MELCON'94, s. 825-8. Antalya, Turkey, 12-14 April 1994.

[3] M. Lewandowski, A.Szeląg, "Minimizing of the output voltage of the chopper inverter", *Archiv. fur Elektrotechnik*, 69,1986, pp.223-226.

[4] M. Lewandowski, "Method of calculations of current harmonics in a current taken from 3kV DC network by a traction vehicle with asynchronous drive", *Przegląd Elektrotechniczny*, pp. 270-275, 6/2010.

[5] A. Mariscotti, G. Armanino, "In-house test of low frequency conducted emissions of static converters for railway application", *Proceedings of the XVII IMEKO World Congress*, Dubrovnik (Croatia), 2003.

[6] A. Magzan, B. Rajkovic, N. Peric, "Possibilities to increase input impedance or power factor of line side converters supplied by DC or AC railway network", Conf. Power Electronics and Variable Speed Drives, 18 - 19 September 2000, IEE 2000.

[7] B. Mellitt, J. A. Taufiq, J. Xiaoping, "Input impedance of chopper equipment and its significance in low-frequency track circuits" *IEE PROC.*, Vol.136, *Pt. B*, No. 1, Jan. 1989.

[8] T. Ogawa, S. Wakao, K. Kondo, N. Terauchi, "Theoretical analysis of return current harmonics in the inverter-controlled DC electric car". 35th Annual IEEE Power Electronic Specialist Conference, Aachen, Germany, 2004.

[9] A. Ogunsola,A. Mariscotti, "*Electromagnetic Compatibility in Railways-Analysis and Management*" ISBN: 978-3-642-30280-0, Lecture Notes in Electrical Engineering, Volume 168, 2013, SPRINGER.

[10] W. Le Roux, B. M. Steyn, "Simulation studies of 50Hz locomotive impedance and DC substation interference sources", *Computers in Railways IX*., WIT Press, 2004.

[11] M. Steczek, "*Methods of determination of input impedance of the electric traction vehicles with converter drives*", (in Polish) Ph.D. Thesis, Warsaw University of Technology, 2012.

[12] M. Steczek A. Szeląg, "Determination of parameters significant for selection of an input filter for a DC catenary supplied electric traction vehicle filter for a DC catenary supplied electric traction vehicle", *Electromotion*, -2/2014 vol. 211.

[13] A. Szeląg, M. Steczek, "3 kV DC system: converter-driven vehicle-signalling circuits compatibility. Criteria and analysis", *Electromotion*, 1/2010, pp. 70-78.

[14] A. Szeląg, M. Steczek, "Analysis of input impedance frequency characteristic of electric vehicles with a.c. motors supplied by 3 kV DC system for reducing disturbances in signalling track circuits caused by the harmonics in the vehicle's current", *Przegląd Elektrotechniczny*, ,pp. 29-33, R.89, Nr 3a/2013.

[15] A. Szeląg A., W. Zając, P. M. Martinez, "Harmonic distortion caused by electric traction vehicles with a.c. motors fed by DC supply system -CAD analysis", *European Power Electronic Conference*, Sevilla, Spain, 18-22 IX 1995, pp. 1.513-1.518.

[16] J. A. Taufiq, J. Xiaoping, "Fast accurate computation of the DC-side harmonics in a traction VSI drive", *IEE Proceedings B*, vol. 136, No. 4, July1989.

[17] EN 50388 standard, "Railway applications - Power supply and rolling stock - Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability (2011)".

[18] W. Zając, A. Szeląg, "Harmonic distortion caused by suburban and underground rolling stock with DC motors", *International Power Electronics Congress CIEP'96*, Mexico, October 14-17, 1996.

[19] W. Zając, A. Szeląg, "Analysis and CAD of electric vehicle power electronic converters as a source of electromagnetic disturbances, *Fourth International Conference COMPRAIL'94*. Madrid 7-9 IX, 1994. Computational Mechanics Publications ISBN: 1 85312 359 5, pp.395-402