FACULTY OF ELECTRICAL ENGINEERING
KTE
September 10 - 12, 2003
Pilsen, Czech Republic

REPRESENTATION OF HARMONIC CURRENTS IN AC TRACTION SYSTEM

ING. DANIELA PRIVRELOVÁ[1]
ING. MARIANA BEŇOVÁ[1]

Abstract: This paper deals with harmonic currents generation and propagation in AC traction system 25kV, 50Hz. With concerning to a stochastic character of harmonic currents is used a probabilistic approach for their representation.

Keywords: current and voltage harmonics, stochastic process, characteristic function, and probability density function.

1 Introduction

The Railway of SR is using two main traction systems, the DC (3kV) and single phase AC (25kV, 50Hz). Both of them derived their power from utility system. This paper takes interest to AC traction system.

A result distortion caused by AC locomotives in traction sector can affect to supply voltage waveform. Voltage waveform distortion in utility system may exercise an influence on other consumers through the common connection point in public electricity supply. Therefore it is necessary to quantify the harmonic current flows into the electricity supply. To eliminate of influence of excessive voltage distortion may require a filter installation.

We take a focus to evaluate the measured data from real traffic and describe simulation possibilities based on probabilistic techniques. The deterministic calculation of each harmonic current consider a steady state, therefore the resultant disturbance is steady. However, the operation of locomotive on a traction feeder is not just steady and the part of harmonic currents has a stochastic character.

[1] Department of Theoretical and Applied Electrical Engineering, Faculty of Electrical Engineering, University of Zilina, Velky Diel 010 26, Žilina. e-mail: privrel@fel.utc.sk, e-mail: benova@fel.utc.sk

2 AC traction system

The power supply of AC traction system is done by the three phase utility system 110kV, 50Hz. It can be realised by phase-fission or by staggered single-phase junction.

2.1 Description of the measured system

Measured system is shown on Fig. 1. This traction substation supplies only one traction sector 22km long. The single-phase transformer connected to utility system feed on secondary side two rails. We have measured the current and voltage harmonics in three points. First was on transformers primary side and the others on secondary side on each rail-feeder.

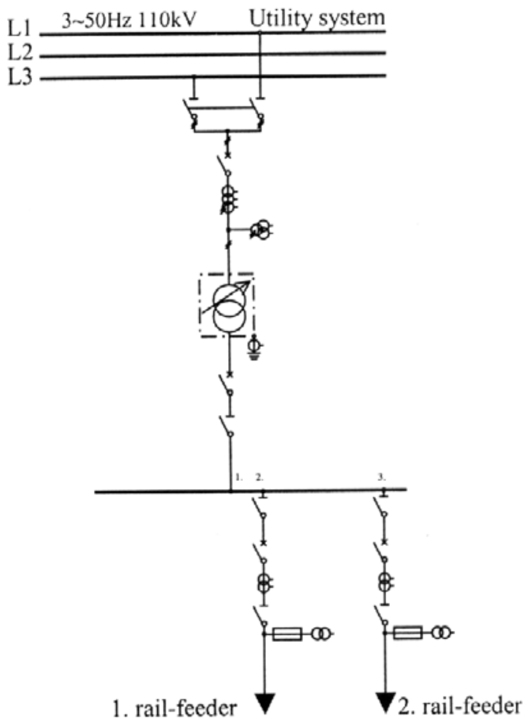


Fig. 1 Measured traction substation

We have realized the long-time measurement, during that was monitored current and voltage harmonics up to 50-th included. In traction sector were operated conventional locomotives with separately excited DC driving motors and impulse control. Duration of locomotive operation in traction sector was from 15 to 45 minutes. For evaluation of harmonic current flow is a worst condition of all the operating modes a locomotive accelerating at maximum tractive effort. We assumed, that in conditions when there are more locomotives at same traction sector, the simultaneous operation at maximum tractive effort is not so likely.

2.1.1 Measured data examples

In following we present results obtained from measured data set. At first here are shown harmonic spectrum of current and voltage at each rail feeder and primary side of transformer in one-day measure duration (Fig. 2 – Fig. 4). With Figure 5 a)-d) (shown harmonic currents scatter diagram in complex plane) we will deal in next chapter. Ratio of harmonic voltages particular in tolerance interval at secondary side shows Tab.1. A Minimum of 95% of all values should be within Tolerance Range. It is evident, that majority of voltage harmonics fall in to the tolerance range, only the fifteenth and twenty-first harmonic exceeds 95% condition, and ninth harmonics is nearby the limit. Voltage harmonics at transformer primary side are all within tolerance range.

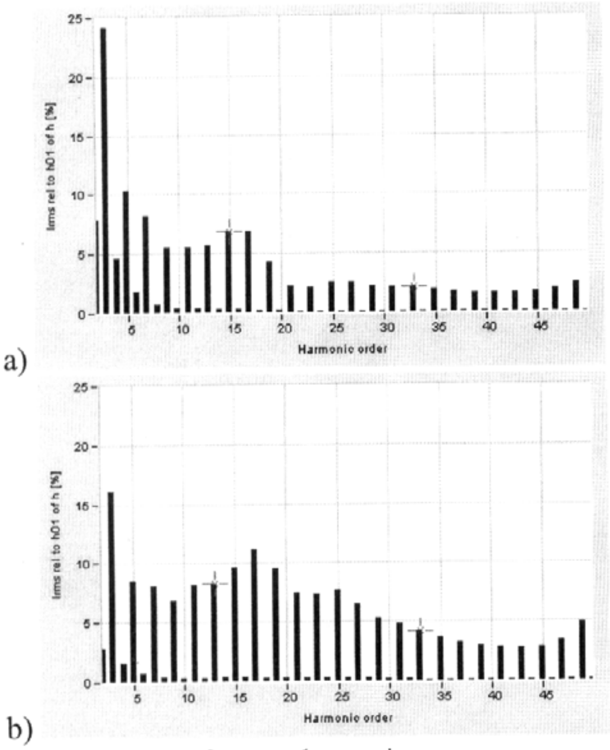


Fig. 2 Spectrum of current harmonics:
a) rail-feeder 1, b) rail-feeder 2

Tab.1 Harmonic Voltages

Harm. order	Tolerance Range %	% of values within Tolerance Range	
		UL1	UL2
THD	0 - 8,00	100,00	100,00
2	0 - 2,00	100,00	100,00
3	0 - 5,00	100,00	100,00
4	0 - 1,00	100,00	100,00
5	0 - 6,00	100,00	100,00
6	0 - 0,50	100,00	100,00
7	0 - 5,00	100,00	100,00
8	0 - 0,50	100,00	100,00
9	0 - 1,50	96,55	96,55
10	0 - 0,50	100,00	100,00
11	0 - 3,50	100,00	100,00
12	0 - 0,50	100,00	100,00
13	0 - 3,00	100,00	100,00
14	0 - 0,50	100,00	100,00
15	0 - 0,50	33,10	33,10
16	0 - 0,50	100,00	100,00
17	0 - 2,00	100,00	100,00
18	0 - 0,50	100,00	100,00
19	0 - 1,50	100,00	100,00
20	0 - 0,50	100,00	100,00
21	0 - 0,50	92,41	92,41
22	0 - 0,50	100,00	100,00
23	0 - 1,50	100,00	100,00
24	0 - 0,50	100,00	100,00
25	0 - 1,50	100,00	100,00

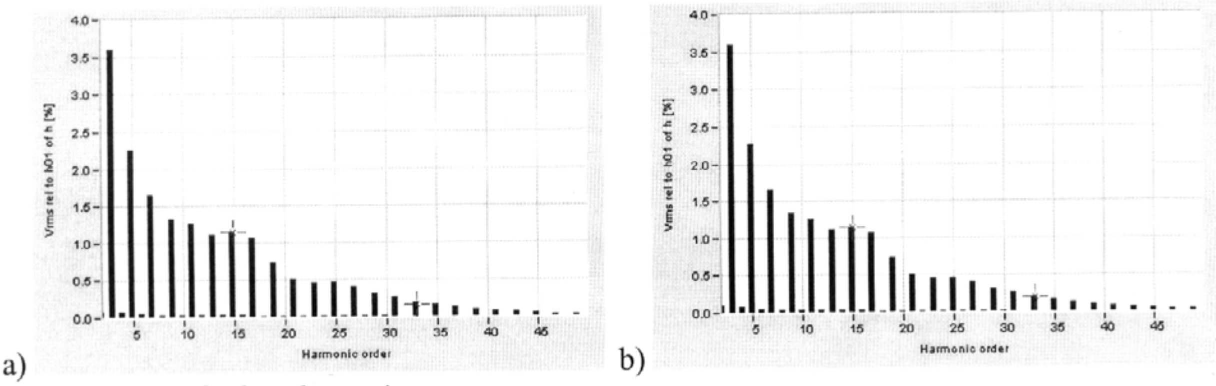


Fig. 3 Spectrum of voltage harmonics:
a) rail-feeder 1, b) rail-feeder 2

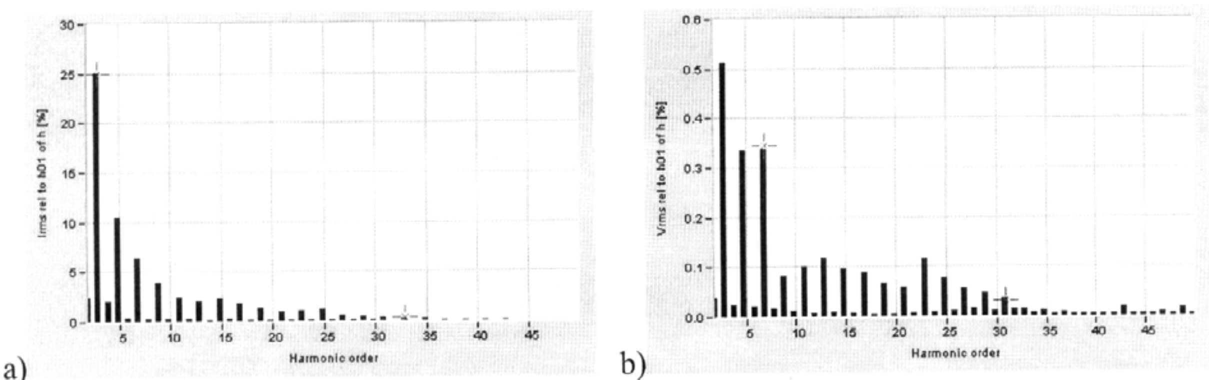


Fig. 4 Spectrum of current and voltage harmonics at primary side of transformer:
a) current, b) voltage

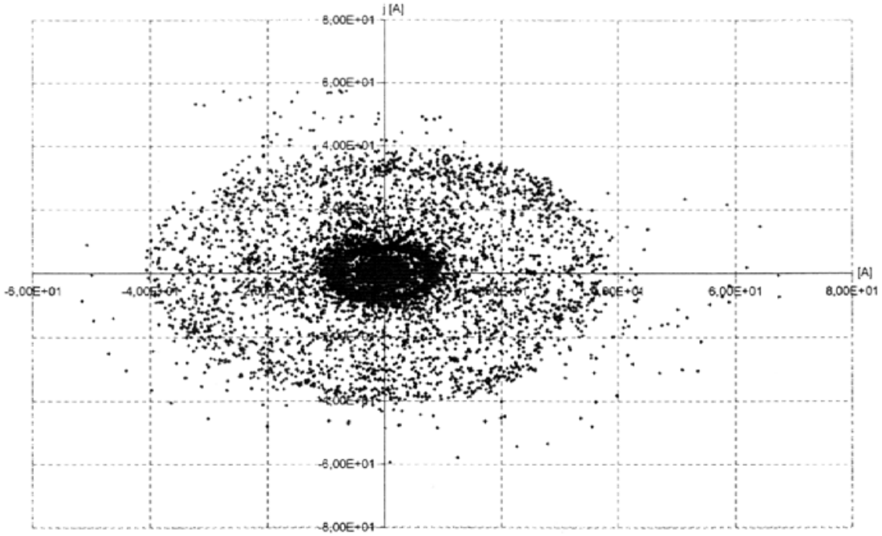
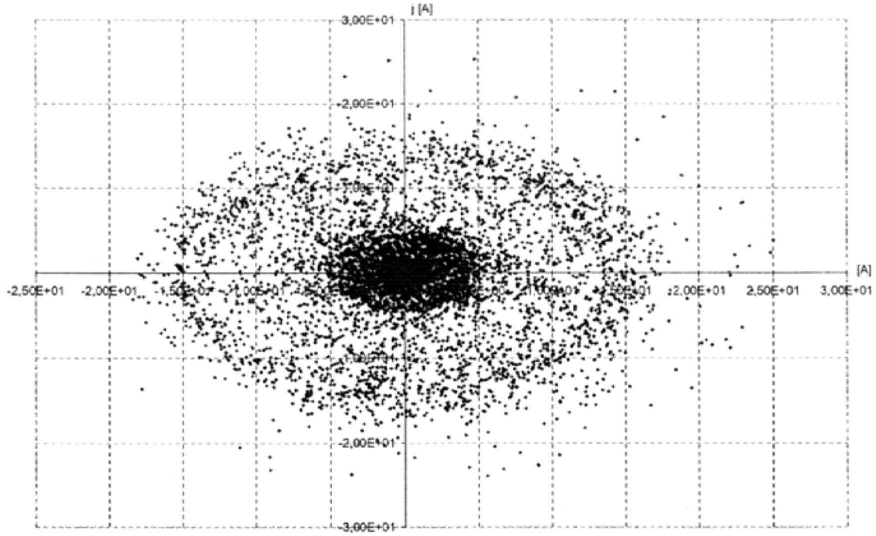
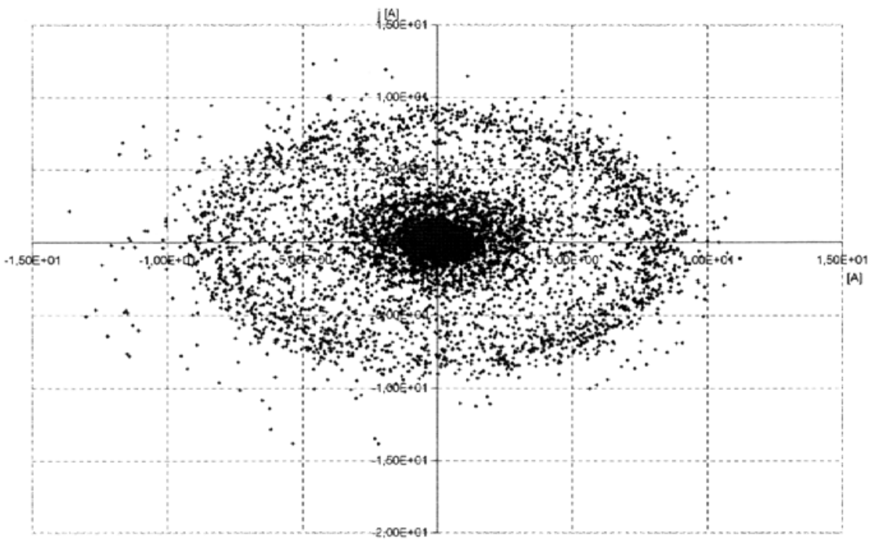


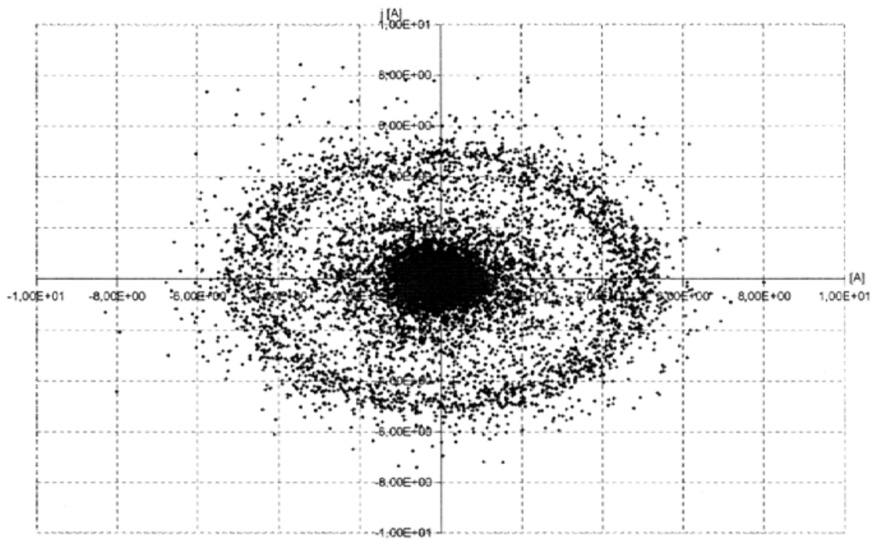
Fig. 5 a) Third harmonic currents scatter diagram in complex plane



b) Fifth harmonic currents scatter diagram in complex plane



c) Seventh harmonic currents scatter diagram in complex plane



d) Ninth harmonic currents scatter diagram in complex plane

3 Probabilistic approach

Each probabilistic formulation requires, at first, the statistical characterization of an input data and then evaluation of statistical features of output variables. The statistical characterization consist from deciding which of a system components can be kept fixed, and what are the statistical features to characterize the random nature of the stochastic variables. For investigation of random variables properties is necessary to obtain their characteristic function.

3.1 Stochastic character of locomotive harmonic currents

Measured data from traction substation were analysed by FFT (Fast Fourier Transformation) and derived the current amplitudes and phases. The scatter diagrams of third, fifth, seventh and ninth harmonic are shown in Fig. 5. This diagrams is including one-day operation of locomotives on one rail feeder. Only one locomotive operating at tractive sector was a rare, but not impossible event.

The deterministic part of locomotive currents can be caused by locomotive operation at steady speed, coasting or braking. During acceleration time, the locomotive currents can be assumed to be random. Each locomotive is assumed as independent harmonic source.

The scatter diagrams in Fig. 5 are shown circular loci of harmonic currents, as were described in [1]. From the all currents of each harmonic is needed to remove the deterministic behaviour. Each random harmonic current is a two dimensional random vector, and can be described by the joint density function, or the marginal density functions of its real and imaginary parts. This probabilistic representation may be derived from measured data by means of real and imaginary component variances and covariance. Next step is to derive from them the marginal random variables probability density function. Thus a two dimensional PDF is needed to represent the each harmonic.

3.2 Probabilistic model of harmonic current propagation

AC traction system components consist of traction single phase transformer connected to utility system, overhead traction line and locomotive – floating load point, which can be represented as a busbar with variable location and load. All of static equipment can be modeled by standard equivalent circuits. The locomotive load can be modeled by PDF for each of harmonic current of his standard spectrum.

The purpose of the load flow study is to obtain the fundamental frequency voltage magnitudes and phase angles. In calculations is the utility system considered as infinite bus.

The Nodal admittance matrix is used for the calculation of the system harmonic voltage

$$\mathbf{Y}_{(n)} = \begin{bmatrix} Y_{11} & -Y_{12} \\ -Y_{21} & Y_{22} \end{bmatrix}$$

The locomotive movements should be described by line relief and railway station distance. The admitance matrix should be defined for all of train locations. Therefore the harmonic admittance matrix is changing consecutive for the each locomotive position. Then the deterministic current can be considered constant, and the random part can be generated by Monte Carlo simulation. The AC system voltage harmonics are evaluated by solving the linear equation system for each harmonic:

$$\mathbf{I}_{(n)} = \mathbf{Y}_{(n)}\mathbf{U}_{(n)}; \quad n > 1$$

4 Conclusions

As result from the measured data, the voltage waveform distortion at traction transformer primary side from chosen data set do not exceeds tolerances. That creates a notion, that the locomotives operation in this traction sector does not require a filter installation. Considering that the complete analyse of measured data is time and technical difficult operation, we will take a definite view later.

The harmonic currents generated by AC traction may be represented as partly random and partly deterministic variables. The random variables may be described by their PDFs. The total n-th harmonic current is composed of a deterministic and random part.

In conclusion we wish to thank to the management of ZSR - The Division of power and electrical engineering, ZSR VVUZ and SSE, a.s. for permission to measurement, borrowing the measurement facilities and permission to use test results.

References

[1.] Morrison R.E., Clark A.D.: Probabilistic representation of harmonic currents in AC traction system, IEE Proceedings, Vol. 131, Pt. B, No. 5, seprember 1984.

[2.] Ribeiro P.F.: Distribution system and other elements modeling, IEEE Transactions On Power Delivery, 2000, www.ieee.org.

[3.] Ortmeyer T.H., Fayyaz Akram M., Hiyama T.: Harmonic Modeling of Networks, IEEE Transactions On Power Delivery, 2000, www.ieee.org.

[4.] Mark Halpin S., Ribeiro P.F., Dai J.J.:Frequency Domain Analysis Techniques, IEEE Transactions On Power Delivery, 2000, www.ieee.org.

[5.] Caramia P., Capirelli G., Rossi F., Verde P.: Probabilistic iterative harmonic analysis of power systems. IEE Proc.-Gener. Transm. Distrib. Vol 141, No 4, July 1994.