# CIRCUIT MODEL OF TRACTION LOAD UNDER NON-SINUSOIDAL CONDITIONS

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**Summary** Article deals with determination of circuit parameters of the traction load under non-sinusoidal conditions. The circuit parameters are defined by new integral transformation of measured non-sinusoidal voltage and current.

**Abstrakt** V článku je popsáno určení obvodových parametrů trakční zátěže při neharmonických průbězích napětí a proudu. Obvodové parametry jsou definovány novou metodou integrální transformace měřených neharmonických průběhů napětí a proudů.

## 1. INTRODUCTION

Properties of an electric equipment are not possible to point out directly, but by means of its model which we form on the basis of measured quantities. There are only two kinds of measureable time functions in electrical engineering - instantaneous values of voltage and current. The measured instantaneous values of time varying functions are expressed by Fourier´s series at present. This approach does not make form a physical model of an electromagnetic phenomenon, because we do have not at disposal its parameters.

The parameters of the physical model of the electromagnetic phenomenon is possible to obtain by means of a new method of integral transformation.

## 2. ELEMENTARY CIRCUIT MODELS

Every electromagnetic phenomenon which is characterized by instantaneous values of voltage and current can be commonly modelled by the sum of three physical laws: Ohm´s law, induction law and equation of continuity. The sum of the physical laws is formed according to Kirchhoff´s laws and principle of duality too (indication $\leftrightarrow$). The principle of duality is a tool of distinguishing and the ability to distinguish is a tool of knowledge. Then we have

$$i_G = Gu \;\leftrightarrow\; u_R = Ri,$$

$$i_C = Cu' \;\leftrightarrow\; u_L = Li',$$

$$i_\Gamma = \Gamma u^x \;\leftrightarrow\; u_D = Di^x$$

where

$$u' = \frac{\mathrm{d}u}{\mathrm{d}t},\; i' = \frac{\mathrm{d}i}{\mathrm{d}t},\; u^x = \int_0^t u \cdot \mathrm{d}\xi + K_1,\; i^x = \int_0^t i \cdot \mathrm{d}\xi + K_2,$$

and every quantity is the alternating periodical functions.

By the sum of the currents

$$i_G + i_C + i_\Gamma = Gu + Cu' + \Gamma u^x = i$$

is modelled a circuit equation of the parallel connection of a resistor, a capacitor and an inductor with parameters $G, C, \Gamma$ (conductance, capacitance, inverse inductance).

By the sum of the voltages

$$u_R + u_L + u_D = Ri + Li' + Di^x = u$$

is modelled a circuit equation of the series connection of a resistor, an inductor and a capacitor with parameters $R, L, D$ (resistance, inductance, inverse capacitance).

The elementary circuit model of the electromagnetic phenomenon is possible to form, according to Kirchhoff´s laws, for a common voltage (a parallel combination of circuit elements) or a common current (a series of combination of circuit elements) only, as shown in Fig.1.

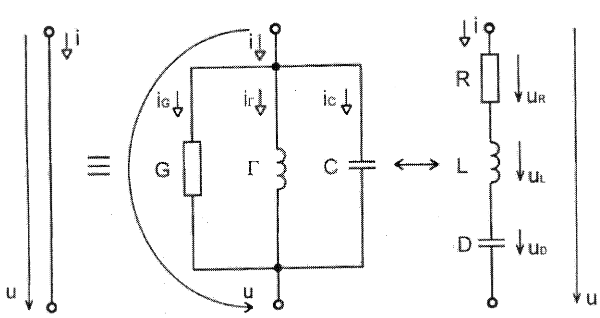



*Fig. 1 The elementary dual circuit models of the alternating periodical electromagnetic phenomenon.*

The parallel elementary circuit model of electromagnetic phenomenon and its series elementary circuit model are dual. The dual pair are the parameters, too

$$R \leftrightarrow G,\quad L \leftrightarrow C,\quad D \leftrightarrow \Gamma.$$

In accordance with the duality principle we must distinguish the six circuit parameters for modelling of electromagnetic phenomenon.

## 3. DEFINITION OF CIRCUIT PARAMETERS

The circuit parameters of the electromagnetic phenomenon under nonsinusoidal periodic alternating conditions are defined by the formulae as shown below. These were derived at our Department [1-3]. The parallel circuit parameters are then.

$$G=\frac{(i,u)}{\|u\|^2},\ C=\frac{(i,u')\cdot\|u^x\|^2+(i,u^x)\cdot\|u\|^2}{\|u'\|^2\cdot\|u^x\|^2-\|u\|^4},$$

$$\Gamma=\frac{(i,u')\cdot\|u\|^2+(i,u^x)\cdot\|u'\|^2}{\|u'\|^2\cdot\|u^x\|^2-\|u\|^4},$$

and series circuit parameters are.

$$R=\frac{(u,i)}{\|i\|^2},\ L=\frac{(u,i')\cdot\|i^x\|^2+(u,i^x)\cdot\|i\|^2}{\|i'\|^2\cdot\|i^x\|^2-\|i\|^4},$$

$$D=\frac{(u,i')\cdot\|i\|^2+(u,i^x)\cdot\|i'\|^2}{\|i'\|^2\cdot\|i^x\|^2-\|i\|^4}.$$

## 4. EXPERIMENTAL RESULTS

An example of the measured electrical quantities are voltage a current waveforms (Fig. 2.) on traction load. The values of the parallel and series circuit parameters have been found by the new method integral transformation, in this case:

$G=6{,}28\ \text{mS}$, $C=5{,}23\ \mu\text{F}$; $\Gamma=1{,}72\ \text{H}^{-1}$ and

$R=109{,}5\ \Omega$; $L=-34{,}5\ \text{mH}$; $D=-25{,}1\,(\text{kF})^{-1}$.

When we insert the determined circuit parameters into Eq. (1) and Eq. (2) we find out that, in this case, determined series circuit parameters do not agree with Kirchhoff´s voltage law, therefore ones do not serve as the correct model. The electromagnetic phenomenon, which is characterized by the measured quantities in Fig. 2, is possible to model by the values of the parallel circuit parameters.

By means of the Kirchhoff´s laws we decide about the physical circuit model of the electromagnetic phenomenon.

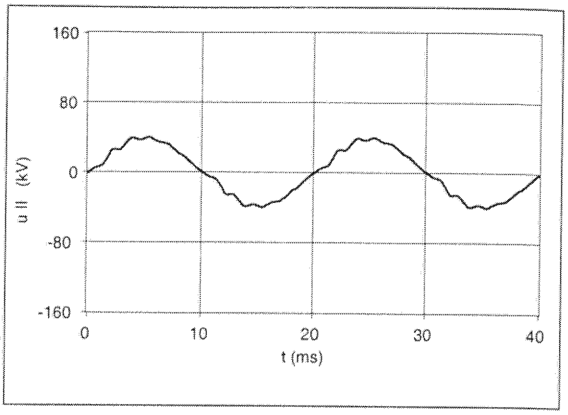
Any electromagnetic phenomenon can be modelled by the values either of the parallel circuit parameters or the series circuit parameters.

The waveforms of derivatives and integrals of the measured electrical quantities have been found out by means of methods of numerical mathematics.

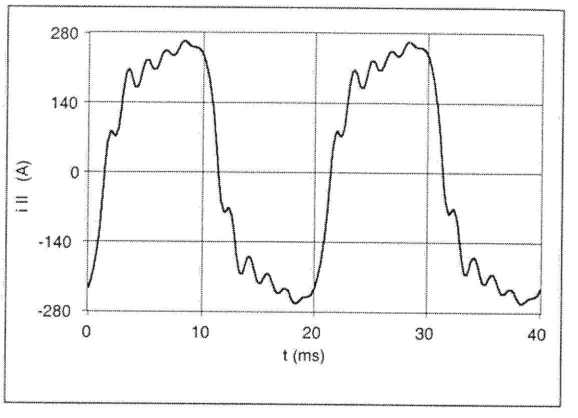
## 5. CONCLUSION

In this paper is described a powerful technique for circuit analyses under nonsinusoidal conditions. The new method is based on a scalar product of time varying quantities and physical properties of real circuit elements. It is an effective tool for production of circuit models of electromagnetic phenomena which are characterized by measured voltage and current.

First we determine the circuit parameters of the electromagnetic phenomenon and then we perform circuit analysis. The purpose of the circuit analysis is to




*a) voltage waveform* $u_{II}=u$, $U=26{,}81$ kV.




*b) current waveform* $i_{II}=i$, $I=203{,}2$ A.

*Fig. 2. Voltage and current waveforms.*

calculate the voltage and current components, which characterize measured phenomenon. Then, on the basis ones, powers, energy and imitances are determined - this part can be presented in next papers.

**Acknowledgement**

The research described in this publication is supported by the Grant Agency of the Czech Republic, grant No. 102/02/1059/A.

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