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CALCULATION OF ELECTROTECHNICAL DEVICES ELECTRIC CIRCUITS WITH INSTANTANEOUS POWER TECHNIQUE

Malyakova M., post-grad.
Kremenchuk Mykhaylo Ostrohradskyi National University
vul. Pershotravneva, 20, Kremenchuk, 39600, Ukraine
E-mail: scenter@kdu.edu.ua

The method of instantaneous power is in-process applied for finding of parameters of linear and nonlinear electric chains. The automated software is developed in the environment of MathCad, based on the vehicle of discrete displacing of two rows, that allows to promote efficiency of calculation of electric chains.

Key words: instantaneous power, nonlinear electric chains, automated software.

Introduction. In the theory of linear electric circuits with permanent parameters an analysis is reduced to the calculation of the system of linear differential or algebraic equations. The matematical apparatus for similar equations is fully developed at the beginning of the last century. Thus for all tasks the principles of superposition and reciprocity are widely used. The calculations of nonlinear electric circuits are much more difficult, as the theory of nonlinear differential equations describing the processes in the nonlinear electric circuits paid less attention to the problem of the development. Each type of equation has its own approach and calculation technique. Many nonlinear equations don't have the analytical solutions and require special function construction.

All methods of analysis of nonlinear circuits can be divided into three large groups: analytical, graphic and numeral [1 - 8]. It is necessary to notice that each of these groups suffers from grave shortcomings: graphic methods do not give availability of general dependences, analytical and numeral, are less demonstrable and more lengthy [1, 2]. The use of these methods is limited with their failings, among them are complication of mathematical expressions with every next approaching and limited exactness [7].

As a result, the analysis of electric circuits with semiconductor elements with the existenting methods can lead to obtaining wrong results , and main to incorrect interpretation of process which takes place in the researched circuit [9].

Objective of work. Increasing of the efficiency of calculation of electrotechnical devices electric circuits with instantaneous power technique.

Materials and findings. The instantaneous power technique [9] is an effective tool for the calculation of the nonlinear electric circuits.The instantaneous power is determined in different ways on the different electric circuits elements [10]:

on power supply

$$p_0(t) = u(t)i(t); \qquad (1)$$

on linear inductance L:

$$p_L(t) = e(t)i(t) = L\frac{d(i(t))}{dt}i(t); \qquad (2)$$

on linear ohmic resistance R

$$p_R(t) = e(t)i(t) = (i(t))^2 R; \qquad (3)$$

on nonlinear inductance L

$$p_L(t) = e(t)i(t) = \frac{d(i(t)L(i))}{dt}i(t); \qquad (4)$$

on nonlinear ohmic resistance R

$$p_{R(t)}(t) = R(t)i^2(t); \qquad (5)$$

$$p_{R(i)}(t) = R(i)i^2(t); \qquad (6)$$

on linear capacity C:

$$p_C(t) = \frac{1}{C}i(t)\int i(t)dt; \qquad (7)$$

on nonlinear capacity C

$$p_{C(t)}(t) = i(t)\int \frac{1}{C(t)}i(t)dt; \qquad (8)$$

$$p_{C(i)}(t) = i(t)\int \frac{1}{C(i)}i(t)dt \qquad (9)$$

According to the instantaneous power technique, the system of balance equations of instantaneous power constant and othorgonal components set up for the power supply and equivalent curuit by the corresponding harmonics is constructing. The algorithm of instantaneous power components calculations is developed for calculations automation. It is based on the theorem about the curtailing, which is known from the theory of signals. The core of this theorem is the Fourier Transformation (FT) of the product of two signals which is the curtailing of their FT [11]. An algorithm is realized by the subsystem of symbolic calculations of the MathCad mathematical package [12].

The calculation of the instantaneous power components of nonlinear electric circuits is realised on the coil with steel (fig. 1) and nonlinear magnetization curve with the sinusoidal current and with the nonsinusoidal current. The block diagrams of the mathematical models for the researched object are presented in fig. 3 and in fig. 4.

The polynomial of 2th degree will apply for the approximation of nonlinear element function L(I) (fig. 2).

$$L(I) = a_0 + a_2 \cdot i^2(t). \qquad (10)$$

It allows one to reach an optimum exactness for obtaining the approximation dependence of given nonlinearity and for obtaining of polynomial coefficients: *a0=0,014288455, a2=-7,83468110-8.*

The automated algorithm of instantaneous power components forming is used for the simplification of the instantaneous power components obtaining process.

The algorithm of instantaneous power components determining on the given nonlinear element is represented in fig. 5

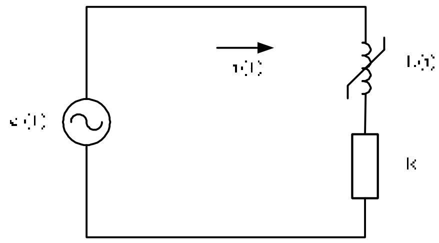


Figure 1 – System of coil with steel

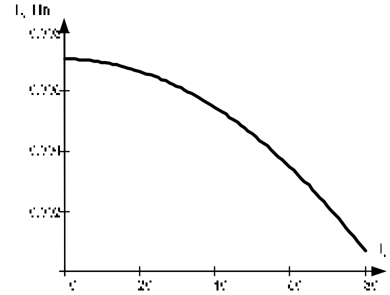


Figure 2 – Nonlinear dependence of inductance on current

The mathematical modeling of the nonlinear systems is realised in the MatLab environment (fig. 3, 4), where the curves of current signals and the spectral composition of instantaneous powers on the elements of the system and instantaneous inductance are obtained (fig. 6, 7).

The harmonic components of instantaneous powers on the elements of mathematical model of the nonlinear circuits are compared with proper values obtained with offered algorithm of equations forming for the instantaneous power components.

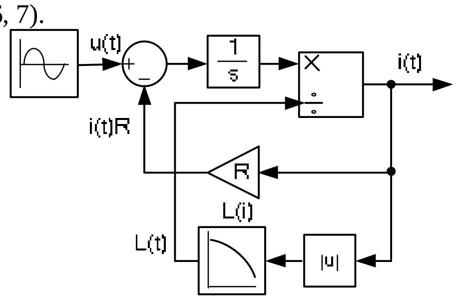


Figure 3 – Block diagram of mathematical model of the system with the sinusoidal supply

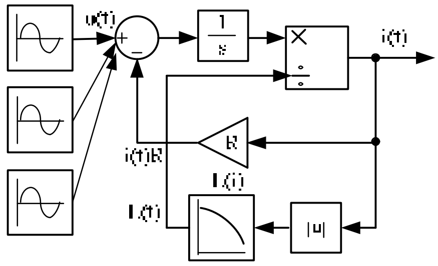


Figure 4 – Block diagram of mathematical model of the system with the sinusoidal supply

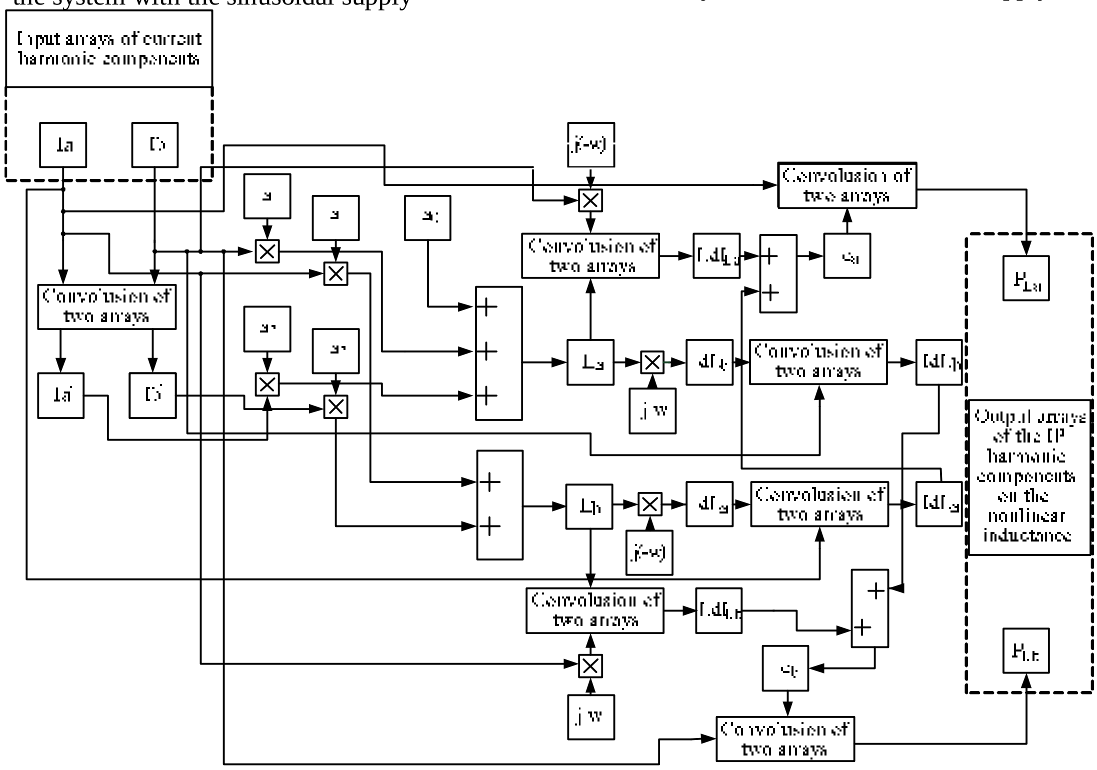
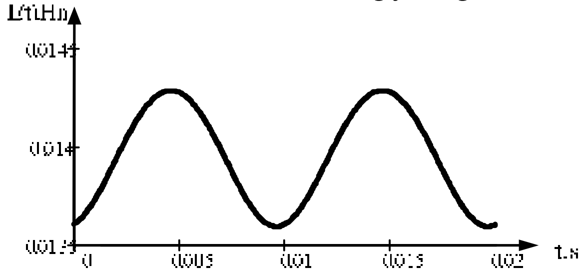
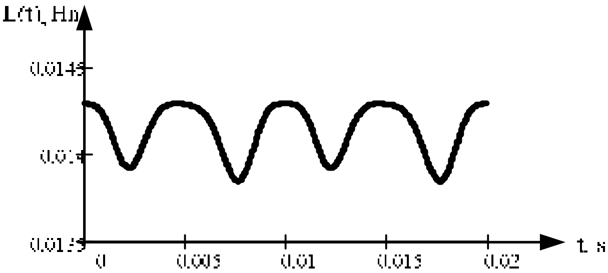


Figure 5 - Algorithm of instantaneous power components determining on the given nonlinear inductance

There are I_a, I_b – input arrays of harmonic components of current, cosine and sine accordingly, P_{La}, P_{Lb} – input arrays of harmonic components IP on the nonlinear inductance, cosine and sine accordingly, a_0, a_1, a_2 – polynomial coefficients, L_a, L_b – harmonic components of nonlinear inductance, cosine and sine accordingly, $L_a dI_a$, $L_b dI_b$ – product of harmonic components of the nonlinear inductance and the input harmonic components of current derivative, cosine and sine accordingly, $I_a dL_a$, $I_b dL_b$ – product of harmonic components of input arrays of current and the input harmonic components of the nonlinear inductance derivative, cosine and sine accordingly in figure 5.



a)



b)

Figure 6 – Curve of L(t) a) – with the sinusoidal supply, b) – with the nonsinusoidal supply

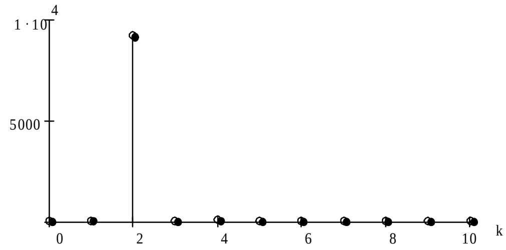
In the capacity of the criteria of estimation of exactness of the getting values of instantaneous power on nonlinear inductance are served:

1. A relative error by the harmonic's paired numbers:

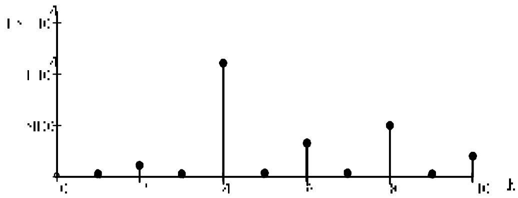
$$d = \frac{X_{åxp} - X_{acc}}{X_{\exp}} \cdot 100\%, \qquad (11)$$

where X_{exp} – a value of power, got by the experimental way; X_{acc} – a value of power, calculated with the reduced algorithm.

It is needed to mark that a relative error is ponderable enough of the power harmonic number, beginning from 4th (table 1).



a)



b)

Figure 7 – Spectral composition of the instantaneous power on the nonlinear inductance a) – with the sinusoidal supply, b) – with the nonsinusoidal supply

Using the followings formulas:

$$P_k = P_{ka}^2 + P_{kb}^2, \qquad (12)$$

$$P_{k\sum} = \sum_{i=0}^{10} P_k^2, \qquad (13)$$

$$s = \frac{P_k}{P_{k\sum}} \cdot 100\%, \qquad (14)$$

will calculate the significance of each harmonic components.

Table 2 reflects, that the second harmonic is the most significant for the system with a sinusoidal supply σ_2=97,75 %, and – fourth harmonic is the most significant for the system with a nonsinusoidal supply σ_2=76,9 %, and errors on them are permissible.

Table 1 – A relative error by the instantaneous power value on the nonlinear inductance

Harmonics	2	4	6	8	10
A relative error by the instantaneous power value on the nonlinear inductance with the sinusoidal supply, %					
Cosine components	0,6	3,3	40	89	90
Sine components	0,06	6,5	69	7	97
A relative error by the instantaneous power value on the nonlinear inductance with the nonsinusoidal supply, %					
Cosine components	12,5	8,7	21,5	19,9	20,2
Sine components	12,3	7,6	9,1	11,3	23,7

Table 2 – Significance of amlitude power components on the nonlinear inductance

Harmonics	0	1	2	3	4	5	6	7	8	9	10
Significance with the sinusoidal supply, %	0	$7{,}6 \cdot 10^{-6}$	$97{,}75 \cdot 10^{-3}$	$2{,}55 \cdot 10^{-3}$	1,5	$7{,}16 \cdot 10^{-6}$	0,6	$7{,}72 \cdot 10^{-6}$	0,37	$5{,}82 \cdot 10^{-6}$	0,07

Significance with the nonsinusoidal supply, %,	0	$9{,}3\cdot10^{-6}$	0,67	$0{,}7\cdot10^{-6}$	76,9	$1{,}4\cdot10^{-6}$	6,1	$1{,}6\cdot10^{-6}$	14,8	$0{,}12\cdot10^{-6}$ 6	0,16

2. A relative error by the effective power signal:

$$d_{ef}=\frac{(\sum p_k{}^2)_{\exp}-(\sum p_k{}^2)_{acc}}{(\sum p_k{}^2)_{\exp}}\cdot 100\%, \qquad (15)$$

where $(\sum P_k{}^2)_{\exp}$ – a value of power, gotten by the experimental way; $(\sum P_k{}^2)_{acc}$ – a value of power, calculated with the reduced algorithm

$$p_k=\sqrt{(p_{a_k})^2+(p_{b_k})^2}, \qquad (16)$$

where Pa_k- cosine component of instantaneous power; Pb_k- sine component of instantaneous power.

Thus, after the calculation we can make a conclusion, that, a relative error by the effective power signal is $d_{ef}=0{,}07\%$, a relative error by the effective power signal is $d_{ef}=1{,}5\%$.

Conclusions. The analysis of the calculations results shows the possibility and efficiency of instantaneous power technique for determining the parameters of electric circuits with different nonlinear elements. The increase in calculation errors takes place at decrease of particular harmonic effect on a general signal and increase of the harmonic number.

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РАСЧЕТ ЭЛЕКТРИЧЕСКИХ ЦЕПЕЙ ЭЛЕКТРОТЕХНИЧЕСКИХ УСТРОЙСТВ МЕТОДОМ МГНОВЕННОЙ МОЩНОСТИ

Малякова М.С., асп.
Кременчугский национальный университет имени Михаила Остроградского
ул. Первомайская, 20, 39600, г. Кременчуг, Украина
E-mail: scenter@polytech.poltava.ua

В работе применен метод мгновенной мощности для нахождения параметров линейных и нелинейных электрических цепей. Разработано автоматизированное программное обеспечение в среде MathCad, основанное на аппарате дискретной свертки двух рядов, что позволяет повысить эффективность расчета электрических цепей.

Ключевые слова: мгновенная мощность, нелинейные электрические цепи, автоматизированное программное обеспечение.

РОЗРАХУНОК ЕЛЕКТРИЧНИХ КІЛ ЕЛЕКТРОТЕХНІЧНИХ ПРИСТРОЇВ МЕТОДОМ МИТТЄВОЇ ПОТУЖНОСТІ

Малякова М.С., асп.
Кременчуцький національний університет імені Михайла Остроградського
вул. Першотравнева, 20, 39600, м. Кременчук, Україна
E-mail: scenter@polytech.poltava.ua

У роботі застосовано метод миттєвої потужності для знаходження параметрів лінійних та нелінійних електричних кіл. Розроблено автоматизоване програмне забезпечення в середовищі MathCad, засноване на апараті дискретної згортки двох рядів, яке дозолить підвищіти ефективність та точність розрахунку електричних кіл.

Ключові слова: миттєва потужність, нелінійні електричні кола, автоматизоване програмне забезпечення