It should be noticed that the source inner impedances can constitute, in a general case, impedances of the transmission system between an ideal source and a load. This fact makes an analysis of a simple power network possible. A suitable calculation example will be presented at the conference.

1. Czarnecki S.Minimization of unbalanced and reactive currents in three-phase asymmetrical circuits with nonsinusoidal voltage // IEE Proc. Part B. – July 1992. – Vol. 139. – No. 4. – P. 347–354. 2. Klinger G. L-C Kompensation and Symmetrierung für Mehrphasesysteme mit beliebigen Spannugsverlauf // ETZ Archiv. – Feb.1979. – N 2. – P. 57–61. 3. Pasko M. Symmetrization of Deformed Three-Phase Current Sypplying Asymmetrical Receiver // 10th European Conference Circuit Theory and Design, Lyngby, September 1991. – P. 1068–1075. 4. Pasko M. Application of LC One-Ports in Phase Load Symmetrization in N-phase Systems with Nonsinusoidal Periodical Waveforms // European Confrence Circuit Theory and Design, Davos, Switzerland, 30 August–3 September 1993. – P. 1159–1164. 5. Pasko M. Selection of the compensators optimizing working conditions of one-phase and multi-phase voltage sources with periodic nonsinusoidal waveforms // (in Polish), Z.N. Pol. Sl. "Elektryka", z.135, Gliwice, 1994. 6. Pasko M., Dębowski K. Selection coefficient for optimum symmetrization in N-phase networks. Acta Techn. CSAV 43. – 1998. – P. 147–159.

УДК 621.311

Marian Pasko, Janusz Walczak, Magdalena Umińska-Bortliczek
Silesian University of Technology, Gliwice (Poland)

OPTIMIZATION OF ELECTRICAL ENERGY QUALITY IN SYSTEMS WITH NONSINUSOIDAL WAVEFORMS

1. INTRODUCTION

Methods and ways of describing power and qualitative properties of systems with nonsinusoidal waveforms have not been unified up to the present. However, the definition of reactive power recommended by International Electrotechnics Committee (IEC) has been changed many times during the last tens of years. Therefore analysis of possibilities of limiting the active power losses and waveform distortion in the systems is complex while the obtained results are often controversial. In the presented project KBN Nr 8T 10a 06811 the following quantities (generally accepted in electrotechnics) have been suggested for describing the analysis and optimization of such systems:

– instantaneous power, active power and apparent power as well as rms values of currents and voltages,

– multicriterial goal functions of the circuit operating conditions which are based on the above-mentioned quantities and they describe the active power (energy) losses and distortion of current voltage waveforms in the systems.

Such a classical initial basis allows one to become independent of many well-known definition of the reactive power and distortion power in the systems with nonsinusoidal waveforms. Moreover, the obtained results have correct physical interpretation and they can be used for synthesis of compensators modifying the system properties in the required way.

2. OPTIMIZATION OF COMPLEX NETWORKS

2.1. Assumptions

To determine the optimized multicriterial goal functions of the complex networks one has assumed the model of a 3-phase system shown in Fig. 1. It consists of three characteristic subsystems:

– a supply one, consisting of n ideal sources of three-phase voltage, each of them is described by the vector $e^k = \{e^k_\alpha\}$, where: $k \in \{1, \ldots n\}$, the number of a source, $\alpha \in \{1, 2, 3\}$ the number of a phase,

– a load one, being a set of m loads consuming the given active powers described by the vector

$$\mathsf{P}^1 = \{P^1_\alpha\}, \quad 1 \in \{1, \ldots, m\}, \quad \alpha \in \{1, 2, 3\}$$

– a transmission one, transmitting the electrical energy between the sources and the system loads.

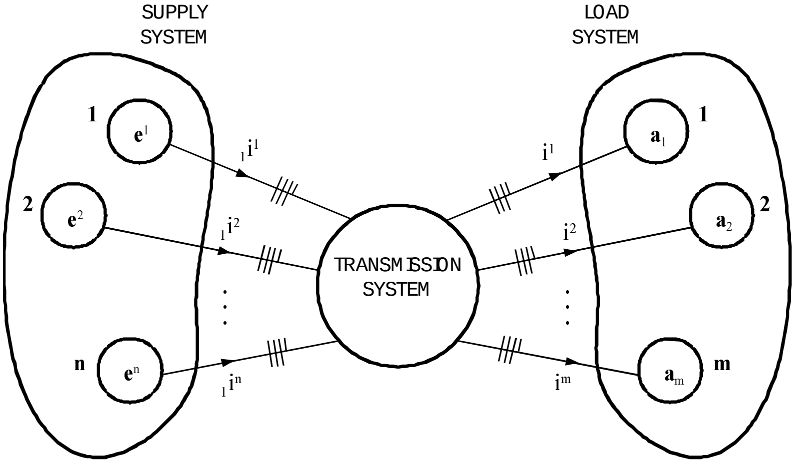

Fig. 1. Model of a network

Each phase of the model presented above contains a nonsinusoidal voltage source and an equivalent load (Fig. 2).

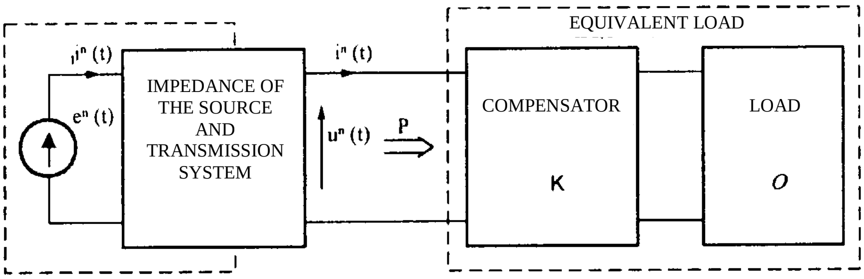

Fig. 2. Model of the n-th phase of a network

The have been considered:
- ideal sources,
- sources with the series impedance,
- sources with the impedance in form of a four-terminal network,
- loads with the parallel compensator,
- loads with the series compensator,
- loads with the series-parallel compensator.

2.2. Basic problems of optimization

The following problems have been formulated and considered for the assumed model (Fig. 2) (they are illustrated in Fig. 3). Waveforms e(t) and i(t) of one phase of the source are illustrated in Fig. 4.

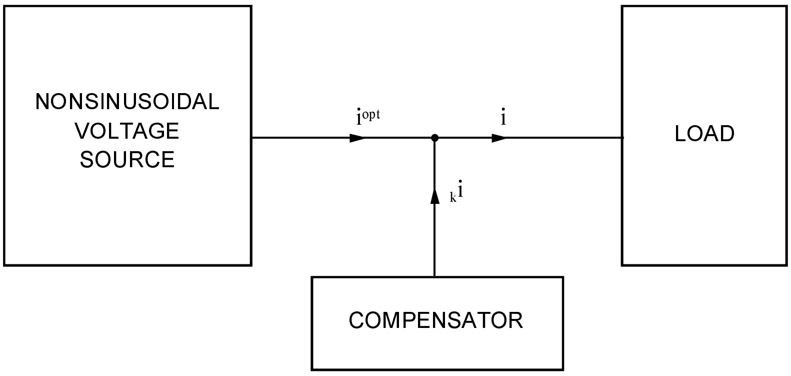

Fig. 3. Model of one-phase of system considered examples 2.2.1 ÷ 2.2.5 by limitations 2.3.2

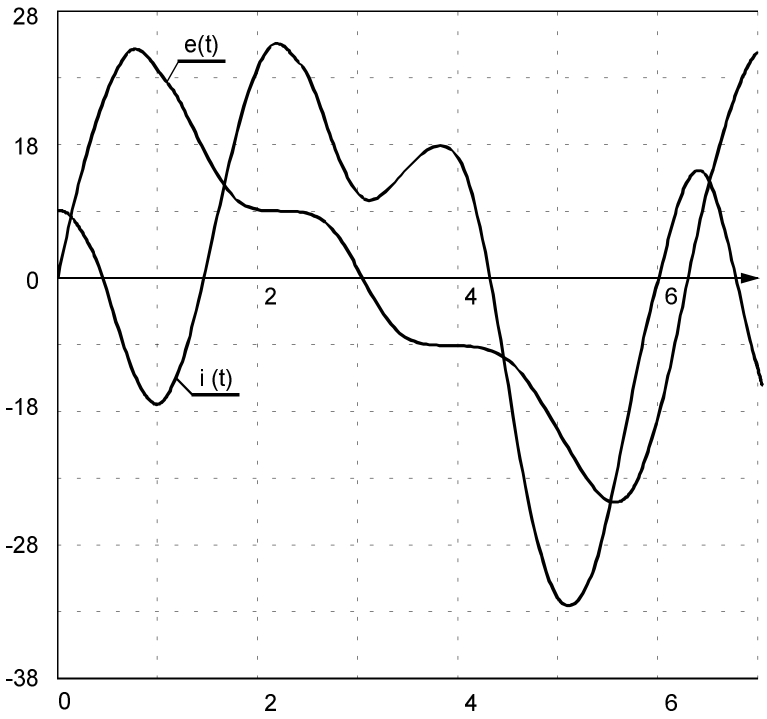

Fig. 4. Waveforms e(t) and i(t) of one phase of the source

2.2.1. Minimization of rms values of the load currents $\mathbf{i}^l$ [1]:

$$\min \min_{\{i^l\}} \left\{ \sum_{l=1}^{m} \frac{1}{T} \int_0^T \sum_{\alpha=1}^{3} \left(i_\alpha^l(t) \right)^2 dt \right\},$$

2.2.2. Minimization of rms values of the source currents [1, 2]:

$$\min_{\{i^k\}} \left\{ \sum_{k=1}^{n} \frac{1}{T} \int_0^T \sum_{\alpha=1}^{3} \left({}_1 i_\alpha^k(t) \right)^2 dt \right\},$$

The result obtained owing to this method is presented in Fig. 5.

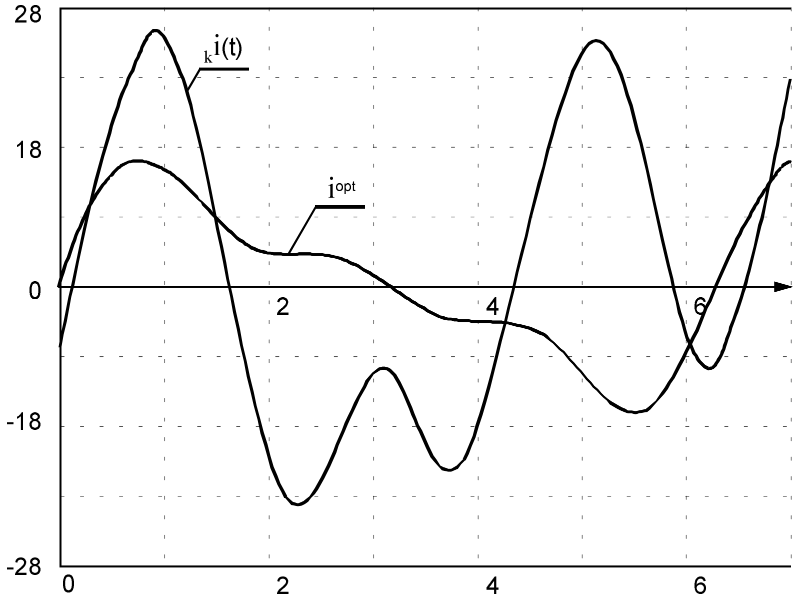

Fig. 5. The result obtained for one phase of the system (Fig. 3) in case of minimization according to formulae 2.2.2

2.2.3. Minimization of the active power losses (power losses) consumed in the transmission system [1]

$$\min_{\{i^l\}} \left\{ \sum_{k=1}^{n} \frac{1}{T} \int_0^T \left(\sum_{\alpha=1}^{3} {}_1 u_\alpha^k(t)\, {}_1 i_\alpha^k(t) dt \right) + \sum_{k=1}^{m} \frac{1}{T} \int_0^T \sum_{\alpha=1}^{3} \left(u_\alpha^k(t) i_\alpha^k(t) dt \right) \right\}$$

2.2.4. Minimization of rms values and distortion of the currents at the load side when taking into account the newly introduced optimization goal function [1] (Sobolev norm of these currents) and limiting the given active powers o the loads [1, 4]:

$$\min_{\{i^l\}} \left\{ \sum_{\beta=0}^{s} \rho_\beta \sum_{l=1}^{m} \frac{1}{T} \int_0^T \sum_{\alpha=1}^{3} \left(D^\beta i_\alpha^l(t) \right)^2 dt \right\}$$

2.2.5. Minimization of rms values and distortion of the currents at the source side (Fig. 1) (Sobolev norm of the source currents [1])

$$\min_{\{{}_1 i^k\}} \left\{ \sum_{\beta=0}^{s} \rho_\beta \sum_{k=1}^{m} \frac{1}{T} \int_0^T \sum_{\alpha=1}^{3} \left(D^\beta\, {}_1 i_\alpha^k(t) \right)^2 dt \right\}$$

where: $u^k = \{u_\alpha^k\}$, $k = 1,\ldots,m, \alpha = 1,\ldots,3$ – the phase voltages across the transmission system at the load side; ${}_l u^l = \{u_\alpha^l\}$ $l = 1,\ldots,n, \alpha = 1,2,3$ – the phase voltages across the transmission system at the source side; D^β – symbol of a derivative of the β^{th} order, $\beta = 0, ..., s$; ρ_β – the weight coefficient.

The results obtained owing to this are presented in Fig. 6:

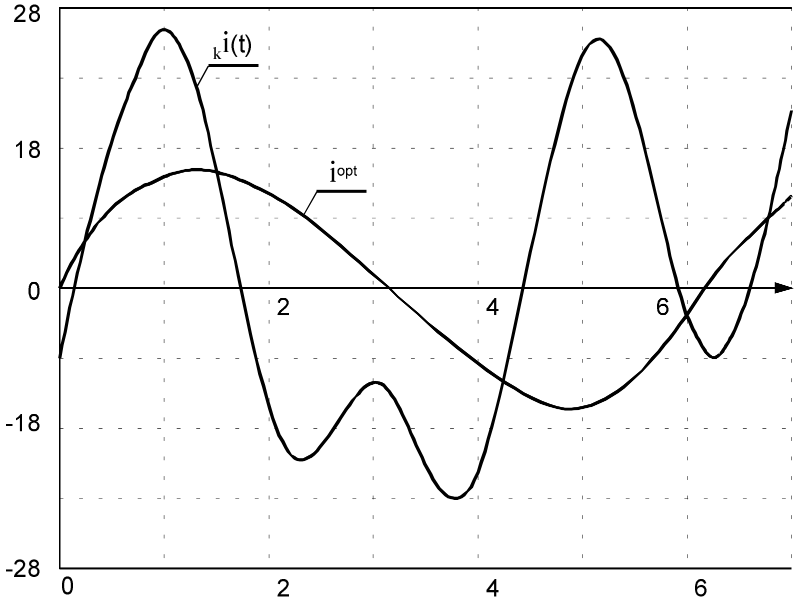

Fig. 6. The result obtained for one phase of the system (Fig. 3) in case of optimization according to formulae 2.2.5

2.3. Realization of the problems

2.3.1. Analysis of the system from Fig.1 has been made for two cases concerning occurance of higher harmonic sources in the system:

1. The harmonic sources in the system are represented by the supply subsystem consisting of the nonsinusoidal voltage sources.

2. The harmonic sources generated by nonlinear loads have been analysed.

2.3.2. Optimization problems formulated in Section 2.2 have been considered when limiting the active powers of the loads $P^l = \{P_\alpha^l\}$, which results in discriminating the set of the network optimal currents of the minimal distortion and minimal rms values. At the some time the given flow of the (phase) active powers to the loads is ensured, which enables symmetrization of the phase powers of these loads. The optimization problems have been formulated in the time domain, next they have been solved in the frequency domain in which the efficient algorithms and numerical programs have been worked out [1].

2.3.3. The methods of harmonic analysis have been used to solve the formulated problems, which has made possible in each of the investigated cases to solve the nonlinear system of algebraic equations in relation to the harmonic currents in the network (Fig. 1).

2.4. Conclusions

The efficient numerical algorithm enabling solution of the above-mentioned optimization problems [1] has been worked out, realised and presented. This algorithm makes possible to determine the optimal voltages and currents at the load terminals, and so it allows to determine the network optimal working point (Fig. 1) according to the optimization problems formulated in Sections 2.2.3, 2.2.4 and 2.2.5.

1. Pasko M., Walczak J. Optymalizacja energetyczno-jakościowych właściwości obwodów elektrycznych z przebiegami okresowymi niesinusoidalnymi. Monografia. Zeszyty Naukowe Politechniki Śląskiej "Elektryka", Gliwice, 1996. – Z. 150. S. 200. 2. Pasko M. Modification of three-phase systems with nonsinusoidal waveforms for optimization of source shape // Archiwum Elektrotechniki, Warszawa, 1995. – T. XLIV. – Z. 1. – P. 69–82. 3. Pasko M., Walczak J. Teoria mocy a technika minimalizacji wyższych harmonicznych. Referat monograficzny wygłoszony na II Seminarium Teorii Elektrotechniki Komitetu Elektrotechniki PAN // Prace Instytutu Elektrotechniki, Warszawa, 1996. – T. XLIV. 4. Walczak J., Pasko M. Zastosowanie metod optymalizacji w teorii mocy obwodów z przebiegami niesinusoidalnymi // Jakość i Użytkowanie Energii Elektrycznej. – 1996. – T. 2. – Z. 1. 5. Walczak J., Pasko M. A New Conception in the Power Theory of Nonsinusoidal Systems // Materiały konf. XIX SPETO'96, Gliwice, 1996. – T. I.

УДК 621.311

Marian Pasko, Janusz Walczak, Magdalena Umińska-Bortliczek
Silesian University of Technology, Gliwice – Poland

SYNTHESIS OF LINEAR, PARAMETRIC AND NONLINEAR COMPENSATORS FOR ELIMINATION OF DISTORTION AND LOSSES OF ACTIVE POWER

1. INTRODUCTION

Various structures of compensators can be obtained due to a network structure, the optimized quality coefficients, the assumed sets of constrains as well as the classes of systems used for compensator realization (SLS, parametric, nonlinear). The solutions of five optimization problems presented in the work [1] are the sets of the optimal active currents ${}_a\mathbf{i}^j = \left\{{}_a\mathbf{i}_\alpha^j\right\}$, of the system presented in the work (Fig. 1). These currents determine explicitly the distribution of the (optimal) voltages in all of the network nodes ${}_a\mathbf{u}^j = \left\{{}_a u_\alpha^j\right\}$, where α – number of the phase, j – number of the source or load.

The optimal working points of the network from Fig.1 [1] are therefore determined by the set of the ordered pairs of the currents and voltages $\left\{{}_a\mathbf{i}^j, {}_a\mathbf{u}^j\right\}_{opt}$. These pairs are the basis for determining the necessary compensators which realize the optimal operating conditions in each of five mentioned cases [1]. To make synthesis of the compensators one uses difference currents which are difference between the primary currents and the determined optimal ones.