P. S. Safronov, Cand. Sc. (Eng.), Ass. Prof.; D. V. Kucherenko; I. V. Bondarenko, Cand. Sc. (Eng.); O. F. Bondarenko, Cand. Sc. (Eng.), Ass. Prof.; V. M. Sydorets, Dc. Sc. (Eng.), Prof.

FORMATION OF CONTROL SIGNAL FOR A MULTIFHASE INTERLEAVED POWER FACTOR CORRECTOR

The paper proposes to use circuit topology with a multiphase interleaved power factor corrector in order to improve electromagnetic compatibility of power sources with the network. The method for realization of the multiphase power factor corrector provides operation of each unified phase in the mode of intermittent current, that is close to boundary current, while the corrector control signal is formed taking into account spectral composition of the input current. This makes it possible to obtain close-to-sinusoidal input current. Using simulation modeling, total harmonic distortion of the circuit under study has been estimated and the efficiency of the proposed solutions has been confirmed.

Key words: *power source, multiphase interleaved power factor corrector, control signal, total harmonic distortion.*

Introduction

Under current conditions of constantly growing number of electronic instruments, devices and systems for domestic and industrial application, which are nonlinear loads for power networks, improvement of electromagnetic compatibility of the consumers with the network is an important direction of research and developments. In this context we should separately mention power sources for electrotechnical installations, such as resistance welding installations, that consume a sharply non-sinusoidal current. This leads to “contamination” of the network and to increased power losses [1].

Along with passive and active filtration, power factor correction is an efficient method to improve electromagnetic compatibility of the power source with the network [2]. This method consists in introduction of a special correction circuit into the power supply circuit (into its input part), which provides consumption of the current by the power sources, the shape of which is close to sinusoidal current.

Building power factor correctors according to the multiphase principle is considered to be a perspective approach to their creation [3, 4]. This approach is relatively new for the domestic research space. Publications dealing with investigation of multiphase interleaved power factor correctors have been appearing, mainly, in foreign editions. The approach consists in the application of several unified correction circuits, connected in parallel, which operate with a phase shift. Advantages of building power factor correctors according to the multiphase principle are as follows: increased power efficiency, reduced pulsations of input and output currents as well as reduced mass and size as compared with correctors built in accordance with traditional single-phase topology [5]. Along with relatively simple construction of the power part of multiphase power factor correctors, it is necessary to solve the problems of rational organization of the control system and control algorithm selection, which can provide the input current shape that will be maximally close to sinusoidal current [6].

The aim of this work is to propose an efficient method for control signal formation by a multiphase power factor corrector, which will enable improvement of the spectral composition of input current, and development of such control system structure for the power part of the corrector, which is capable of this method implementation.

Generalized structure of the multiphase power factor corrector and its operating principle

The multiphase power factor corrector is built in the form of N unified phases, connected in parallel. Each of them is a pulse DC boost converter [3, 4]. A generalized structure of the multiphase converter is shown in Fig. 1. The number of phases N could vary from two to more phases. The choice of the number of phases is determined by specific requirements to input current quality, the structure of control system and expediency considerations.

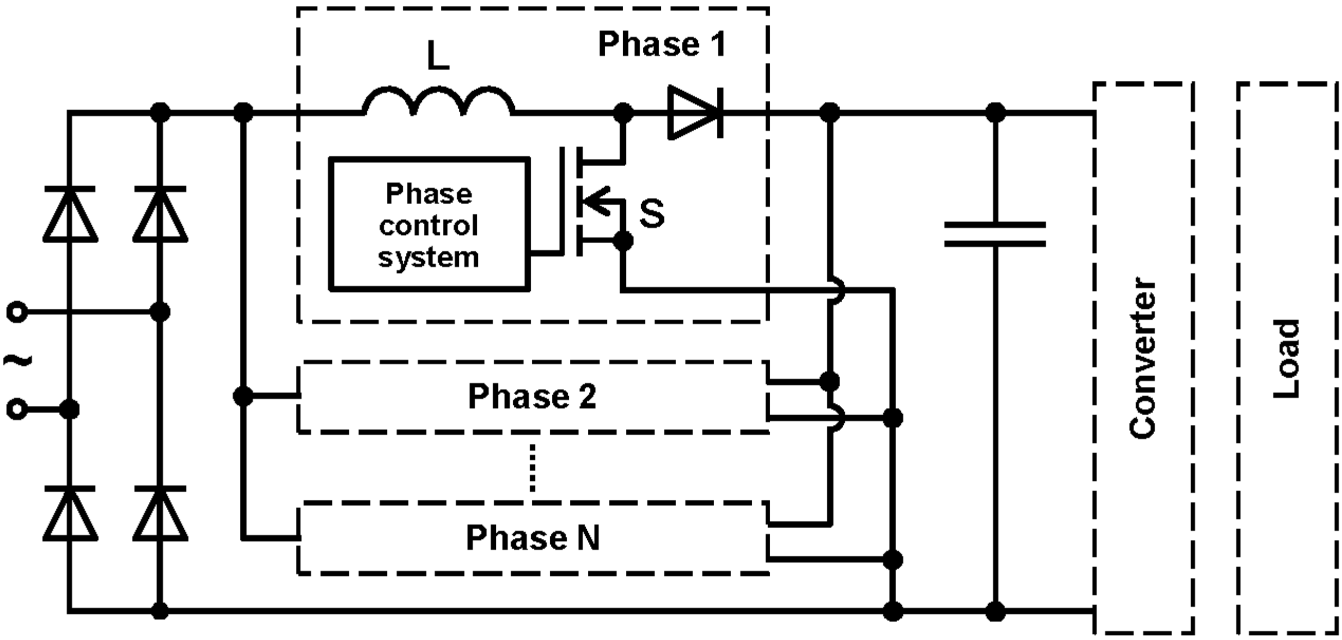

Fig. 1. A generalized structure of the multiphase power factor corrector

Correction phases can operate in the mode of continuous current of accumulative inductance L, in the intermittent current mode or in the boundary mode. With single-phase correction, the best input current shape is achieved using the mode of continuous current of accumulative inductance. However, this mode is not so power efficient as compared with two others. For multiphase correction a close-to-sinusoidal shape of input current, which is the sum of the phase currents (i_1, i_2, ... i_N) shifted relative to each other, can be obtained using a more power-efficient boundary mode of phase operation or the mode of intermittent current, which is close to boundary mode (Fig. 2). Thus, application of multiphase correction makes it possible to improve both the input current shape and to increase power efficiency of the circuit.

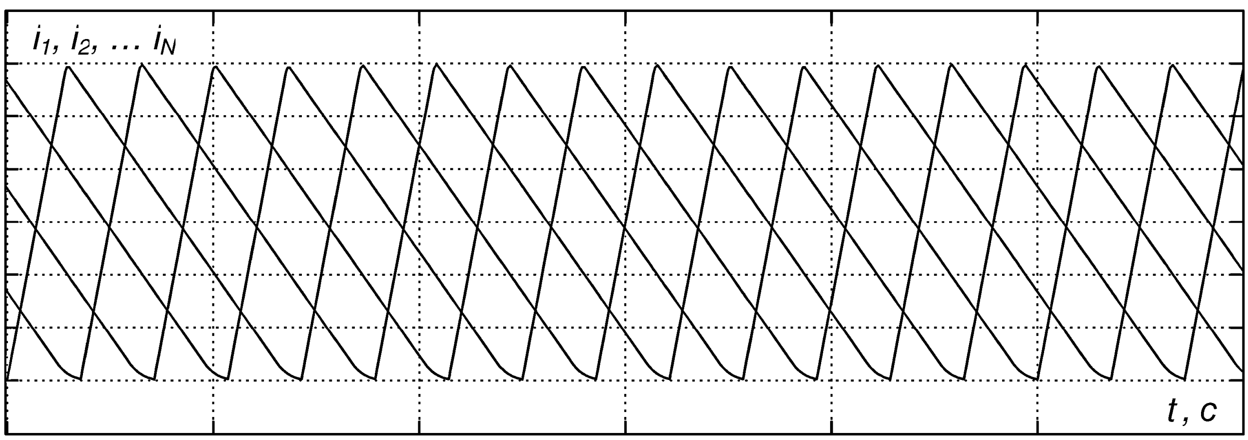

Fig. 2. Enlarged fragment of the diagrams of the currents of phases shifted relative to each other

Control system structure and the method of control signal formation by the multiphase corrector

For controlling the multiphase power factor corrector ready microcircuits of specialized controllers could be used, which are designed, as a rule, for controlling two phases, as well as circuits having unique structures.

Advantages and drawbacks of both approaches are evident. It should be noted, however, that the second variant gives more possibilities for optimization of the power part (the choice of optimal quantity of phases) and of the control modes.

Fig. 3 presents a structure of the proposed control system of one correction phase. Operation principle of the circuit and control signal formation method, that it realizes, are described below.

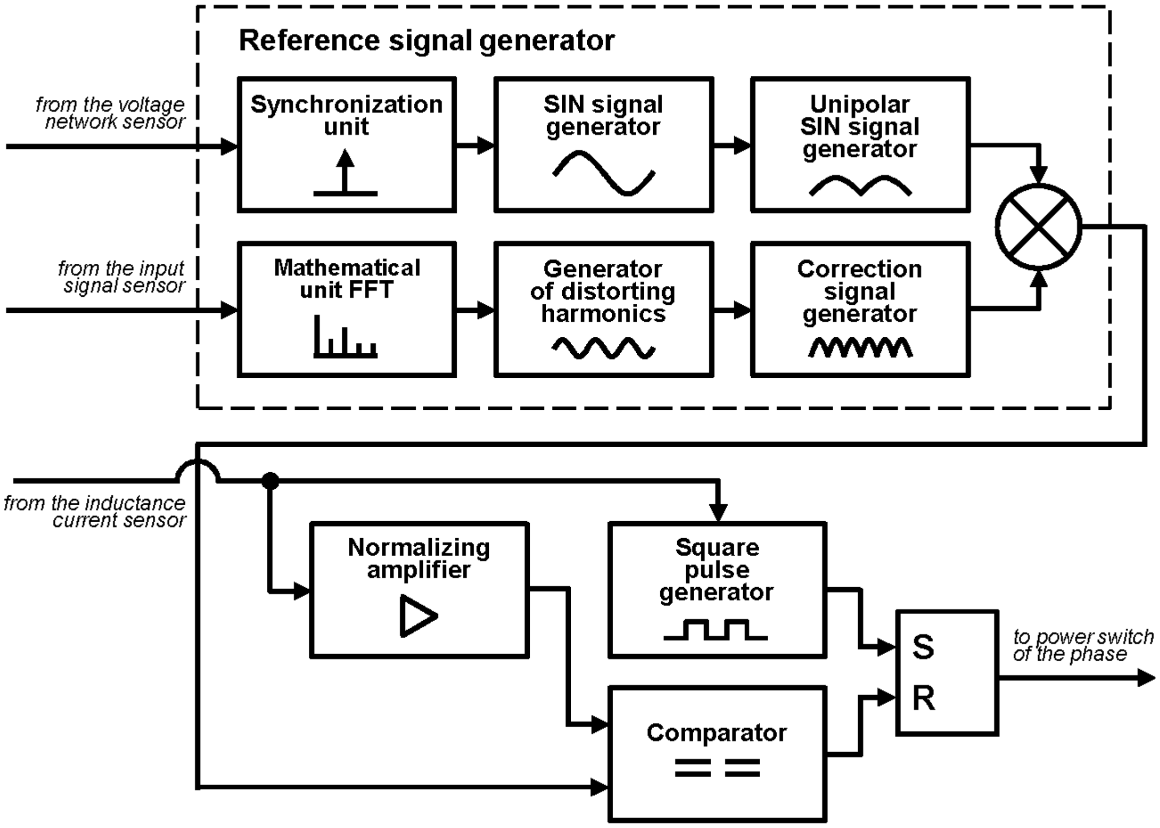

Fig. 3. Structure of the control system of the power factor corrector phase

Immediately after the circuit starts operation, the square pulse generator sets the trigger and turns on power switch S of the corrector phase. Reference signal generator forms a curve that limits growth of the current in inductance L of the corrector phase. The comparator compares signals from the reference signal generator with those from the normalizing amplifier and, when the normalizing amplifier signal reaches current level of the reference signal, it resets the trigger, which, in turn, turns off the power switch S of the phase. So, the current of each phase varies in the range from zero to current value of the reference signal.

Shift between the currents of correction phases is calculated by the formula:

$$\varphi = (i - 1) \cdot T / N, \qquad (1)$$

where T is square signal period; N – number of correction phases; i – phase number.

Frequency of pulses, formed by the square-pulse generator, is preliminary calculated taking into account the value of current in the phase inductance so that close-to-boundary current mode is provided.

In order to achieve maximal approximation of the input current shape to sinusoidal current, phase signal is formed by adding distorting harmonics (of the correction signal) in counterphase to the reference signal. Reference signal is formed as follows. First, the sinusoidal signal generator forms a signal, synchronized with the network current by means of synchronization unit, and then the unipolar SIN signal generator calculates its absolute value. Correction signal formation is realized in the following way. Generator of distorting harmonics creates a corresponding signal by means of fast Fourier transformation of the input current signal, which is performed by the mathematical unit FFT. Then the correction signal generator computes its absolute value. Reference signal correction is carried out with a delay, caused by the time required for fast Fourier transformation and correction signal computation.

Using simulation modeling, quality of the input current of the power supply for resistance microwelding was investigated without application of the power factor corrector and with its application. For this, two different methods for forming multiphase corrector control signals were used, including the method described above. Quantitative estimation of the input current quality was carried out by calculation of the total harmonic distortion (*THDi*):

$$THDi = \frac{\sqrt{i_2^2 + i_3^2 + ... + i_k^2}}{i_1}, \quad (2)$$

where i_1 – amplitude of fundamental harmonic of the input current; i_2, i_3, i_k, – amplitudes of the higher harmonics of the input current.

Fig. 4 shows diagrams of the input current of the power supply for resistance microwelding, obtained as a result of simulation modeling: without application of the power factor corrector; with the application of four-phase power factor corrector but without addition of the correction signal; (c) with the application of four-phase correction and the addition of correction signal.

As it is evident from Fig. 4, when control signals are formed by the corrector without “admixture” of correction signal, input current shape has significant distortions (Fig. 4 b), while when the proposed method is used, the input signal shape is almost sinusoidal (Fig. 4 c). Quantitative estimation of the input current quality has shown the following: if the power factor corrector is not used, total harmonic distortion of current (*THDi*) was 158,6%; with the application of four-phase power factor corrector without “admixture” of the correction signal – 27,9%; with the application of the proposed method for correction signal formation – 4,7%. In the last case *THDi* value corresponds to both domestic and European indices of electric energy quality.

Conclusions

As the simulation results have shown, the proposed method of control signal formation by multiphase power factor correctors makes it possible to obtain current, which is maximally approximated to sinusoidal current. At the same time, quantitative estimation of the input current quality has demonstrated its correspondence to the requirements of the respective standards of electric energy quality.

Further research on this topic is planned to be carried out in the direction of the multiphase corrector structure optimization: choice and substantiation of the number of unified correction phases as well as determination of the relationship between the number of phases and input current quality. Of interest is also investigation and comparison of different control modes used in the circuits of multiphase correctors.

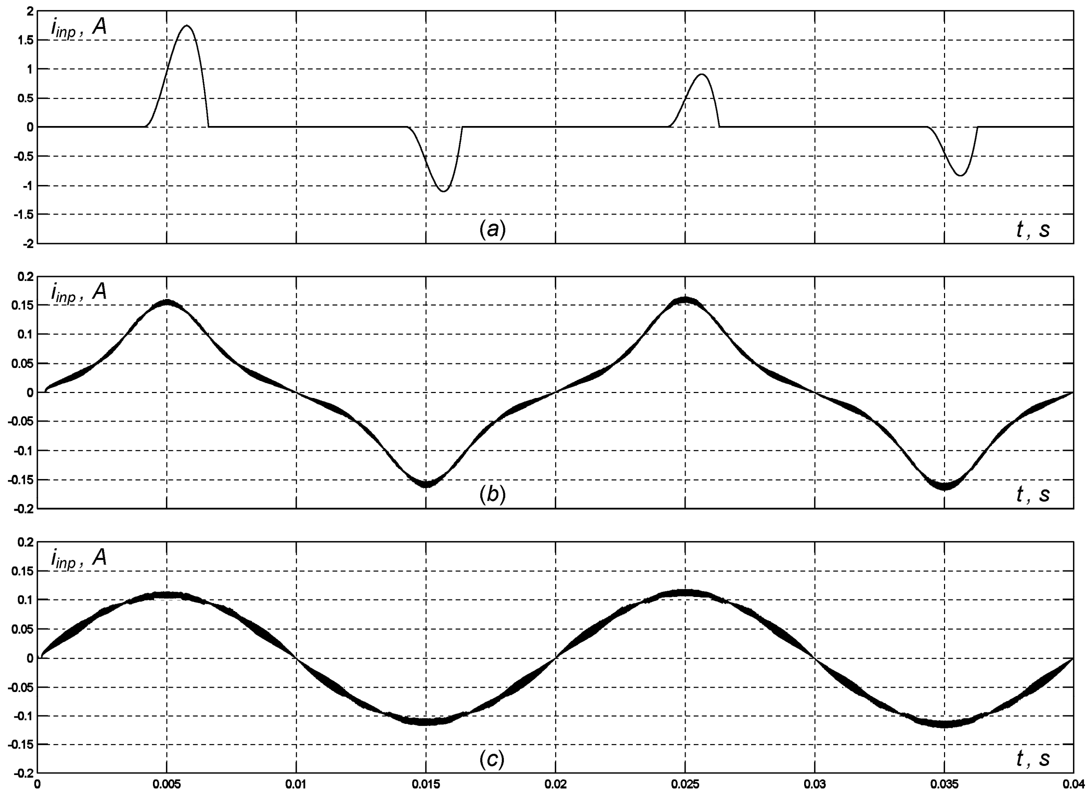

Fig. 4. Diagrams of the input current of resistance microwelding power supply, obtained as a result of simulation

REFERENCES

1. Письменний О. О. Підвищення ефективності систем живлення машин для контактного точкового зварювання: автореф. дис. на здобуття ступеня канд. техн. наук : 05.03.06 «Зварювання та споріднені процеси і технології» / О. О. Письменний. – Інститут електрозварювання ім. Є.О. Патона НАНУ. – Київ, 2008. – 17 с.

2. Транзисторные преобразователи с улучшенной электромагнитной совместимостью / [А. К. Шидловский и др.]. – Київ: Наук. думка, 1993. – 272 с.

3. Schafmeister F. Scalable Multi Phase Interleaved Boundary Mode PFC Concept enabling Energy- and Cost Efficient PSUs in the kW-Range / F. Schafmeister, X. Wang, T. Grote, P. Ide // Proceedings of IEEE International Symposium on Industrial Electronics. – 2010. – P. 3831 – 3835.

4. Grote T. Digital Control Strategy for Multi-Phase Interleaved Boundary Mode and DCM Boost PFC Converters / T. Grote, H. Figge, N. Fröhleke, J. Böcker, F. Schafmeister // Proceedings of IEEE Energy Conversion Congress and Exposition. – 2011. – P. 3186 – 3192.

5. Zambada J. Interleaved Power Factor Correction. [Електронний ресурс] / Режим доступу: http://www.microchip.com/webinars.microchip.com/WebinarDetails.aspx?dDocName=en548529.

6. Xu P. Multiphase Voltage Regulator Modules with Magnetic Integration to Power Microprocessors: PhD thesis / Xu P. – Virginia Polytechnic Institute and State University. – Blacksburg, 2002. – 204 p.

Safronov Pavlo – Cand. Sc. (Eng.), Ass. Prof. of the Department of Electronic Systems of Donbass State Technical University, p.s.safronov@gmail.com.

Kucherenko Dmytro – Postgraduate student of the Department of Electronic Systems of Donbass State Technical University, revolt.kdv@gmail.com.

Bondarenko Iuliia – Cand. Sc. (Eng.), Ass. Prof. of the Department of Electronic systems of Donbass State Technical University, bondarenko.julie@gmail.com.

Bondarenko Oleksandr – Cand. Sc., Ass. Prof. of the Industrial Electronics Department of National Technical University of Ukraine "Kyiv Polytechnic Institute", bondarenkoaf@gmail.com.

Sydorets Volodymyr – Dc. Sc. (Eng.), Prof., Leading Researcher of Gas Discharge and Plasma Engineering Department of Paton Electric Welding Institute of NAS, sydorvn@gmail.com.