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ACTIVE POWER FILTER FOR REACTIVE POWER COMPENSATION FOR THE POWERFUL SOUNDING PULSES SHAPERS

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The expediency of using a power active filter in the mode of reactive power compensation of the supply network for the powerful sounding pulses shaper power supply system of the Institute of ionosphere NAS and MES of Ukraine is shown. An analysis of the literature has been carried out, which shows the effectiveness of solving the problem of reactive power compensation, filtering higher harmonics of the power supply network using an additional energy source to obtain a compensating signal in the form of current or voltage. The choice of the power circuit for constructing an active filter has been made. A voltage inverter on IGBT transistors is used as a power active filter. The basic principles of operation of the power active filter control system are described, which are based on the p-q theory of power and provide for the calculation of instantaneous values of the task currents for each phase of a three-phase power supply system. The work of the Matlab-model of the power supply system of the shaper is shown; the oscillograms of the main energy characteristics of the shaper are given. As a result of using a power active filter, the current of the supply network becomes close to sinusoidal, and the power factor tends to 1. A positive effect on the efficiency of the shaper when the power active filter is included in the supply network is noted, which is due to the efficiency of compensation of the reactive power consumed by the shaper from the supply network. The simulation results are presented, in particular, graphs of reactive power change at the point of connecting the power active filter to the supply network, at different levels of reactive power consumption by the shaper. The results obtained confirmed the possibility of using a power active filter in the mode of reactive power compensation of the supply network when solving the problems of improving the electromagnetic compatibility of powerful sounding pulses shapers with the supply network, reducing losses and increasing the reliability of the shapers.

Key words: *power active filter, reactive power control, control systems*

1. Introduction

The issues of reactive power compensation and payment for the flow of reactive electricity are very relevant at the present time. Compensation of reactive loads can be attributed to the most effective energy-saving technologies in electrical networks of consumers and power systems. Also, the increased requirements for the quality of electricity consumed from the supply network led to the emergence of a number of scientific works aimed at developing devices and methods to reduce the influence of electricity consumers on the supply network [1–7]. These devices include reactive power compensators and active power filters (APF).

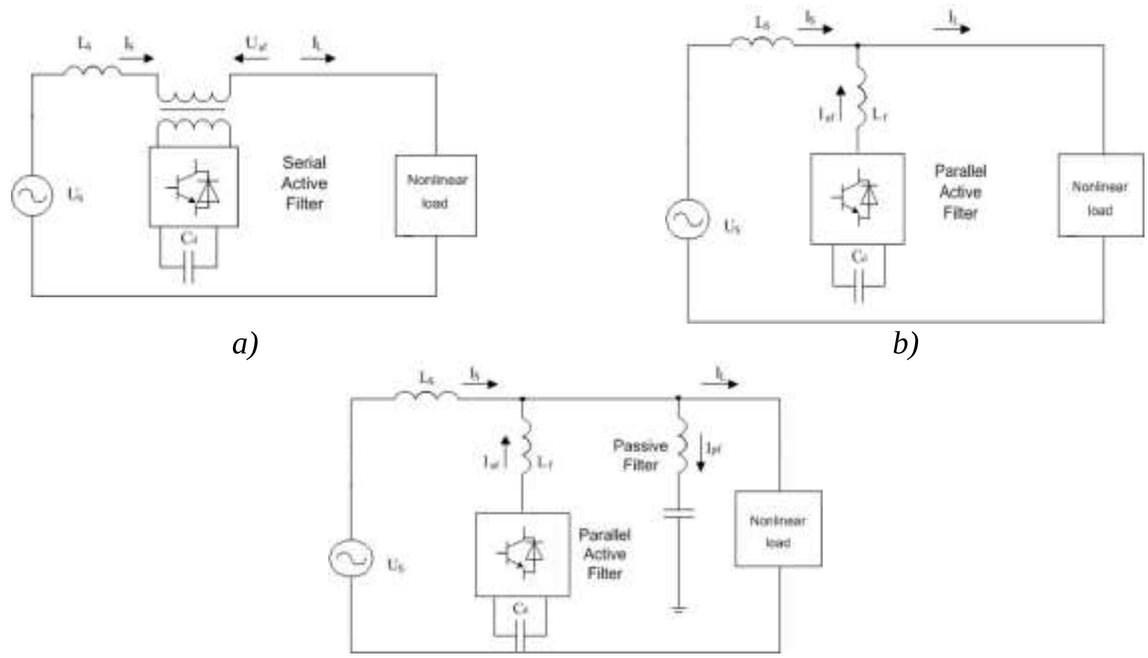
Non-linear loads, the operation of which is accompanied by distortion of the network current shape and the consumption of reactive power, are among the electricity consumers that most negatively affect the supply network. Elimination of negative factors is possible by using the APF, the main tasks of which are to compensate the distortion of the current shape and to provide zero phase shift of the current and voltage curves at the point where the APF and the load are connected to the supply network.

The principle of operation of the APF is that a controlled converter in its composition, using the energy of a current or voltage source, generates a current similar in harmonic composition to the load current (except for the first harmonic), but opposite in sign. As a result, there is a mutual compensation of higher harmonics of the non-linear current and the controlled converter of APF. A direct frequency converters, a current and voltage inverter, and controlled switches are used as converters of power active filters.

The purpose of the work is to study the operation of an active power filter and its control system in the reactive power compensation mode for the power supply system of the powerful sounding pulses shaper which belongs to the Institute of ionosphere of the National Academy of Sciences and the Ministry of Education and Science of Ukraine [8].

2. Power active filter topologies

In fig. 1 typical structures of active power filters are shown: serial active filter (Fig. 1*a*), shunt active filter (Fig. 1*b*) and hybrid active power filter types (Fig. 1*c*). Serial is used as non-sinusoidal voltage compensator, shunt APF is used as non-sinusoidal current compensator.



a) *b)* *c)*

Fig. 1. Typical structures of active power filters

The relationship between the functionality of serial active filters, shunt active filters and hybrid filters, their topology, and implementation features of the control system are considered in [1–7]. Systems with connection of APF in parallel with load are characterized by big opportunities of attenuation of the higher harmonics of current of a network, and as a consequence, good filtering characteristics [2, 6].

Fig. 2 shows the system network – non-linear load with a shunt active filter. The active filter can be made on the basis of a voltage or current inverter connected in parallel to the load and regulated in such a way that its current is equal to the total current of the higher harmonics of the load.

The works [5, 7] present the results of the development of a three-phase four-wire parallel active filter based on a two-level voltage inverter, made on fully controllable power elements – bipolar transistors with an insulated gate (Fig. 3).

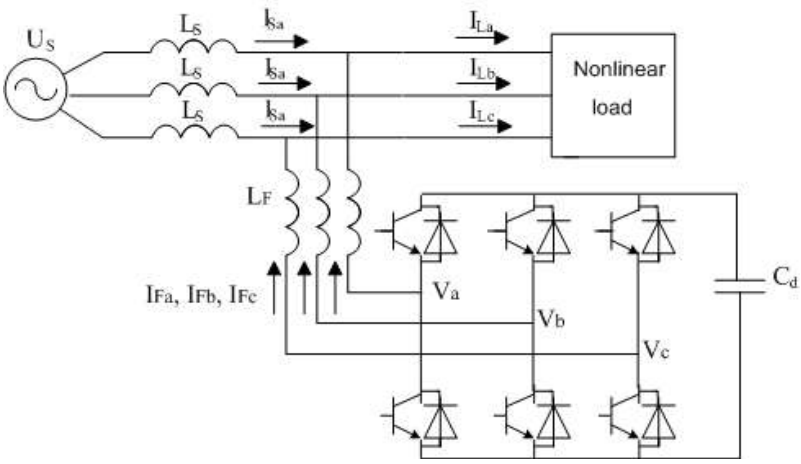


Fig. 2. Typical structure of shunt active power filter

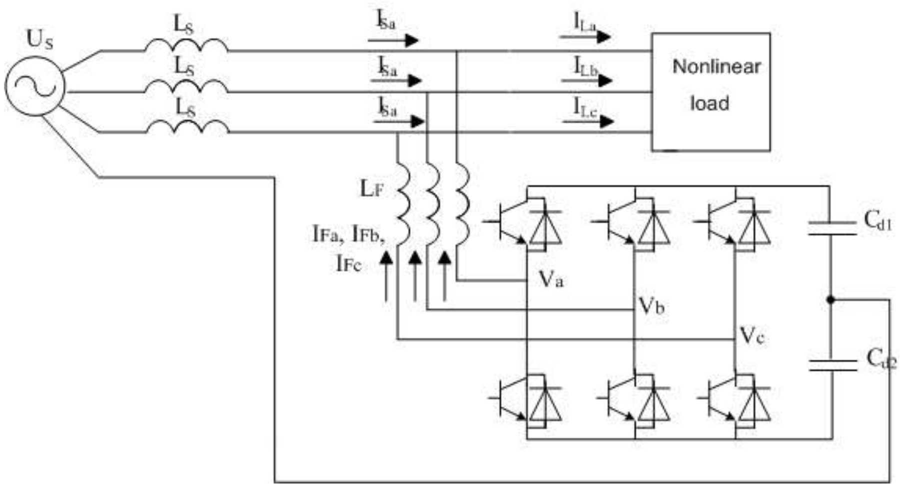


Fig. 3. Three-phase four-wire shunt active power filter

3. Control principles of APF and Matlab-model

This article presents a simulation results of the active power filter circuit, built on the typology, which is shown in Fig. 2.

The most complex component of the power active filter, on which the compensation efficiency mainly depends, is the control system that forms the required switching algorithm for semiconductor switches of the APF converter.

The operation of the APF control system is based on the measurement of the phase currents of the load and the filter by means of two sets of corresponding sensors.

Ideally, with full compensation of the higher harmonics and reactive power consumed by the load, the total load current and APF are sinusoidal and in phase with the supply voltage, i.e. the load-APF system consumes only active power from the network. Therefore, if the active component of the first harmonic is subtracted from the load current, the resulting signal will qualitatively and quantitatively characterize the degree of distortion of the initial current. The APF management strategy is described below.

Analytically, the above can be expressed as an equation:

$$i_{ref}(t)=\left[i_L(t)-i_{1L}(t)\right]\frac{1}{k}, \qquad (1)$$

where $i_{ref}(t)$ – reference current; $i_L(t)$ – instantaneous value of load current; i_{1L} – the first harmonic of the active component of the load current; k – a constant factor that binds the signal with a APF.

The efficiency of the APF is largely determined by the accuracy of the formation, which depends on the distortion of the voltage shape of the supply network and the speed of the control system units that implement mathematical operations.

Inaccuracy in determining the reference current leads to incomplete compensation of the higher harmonics of the load current, overload of the elements of the power circuit of the APF and additional power losses.

The principle of connecting the APF and sounding pulses shaper to the mains is shown in Fig. 4. Shaper generates, amplifies and transmits powerful sounding pulses and is built according to a two-channel scheme, each channel of which is a pulse transmitter generating high-frequency sounding pulses. Each channel of the transmitter contains: a high-voltage rectifier (HVR), a modulation device (MD) – storage line (six parallel-connected modulator cells (MC1 – MC6) in Fig. 4), a preamplifier, a pulse transformer (PT) and a three-stage power amplifier. The transmitter operation is described in detail in [4].

Basic elements of the APF control system structure based on p-q power theory is shown in Fig. 5. It contains the source power supply, voltage inverter, storage Cd, nonlinear load - sounding pulses shaper.

The signal from the network current sensors 1 – 3 carries information about the instantaneous values of the active and inactive load power. The signals from the output of the voltage sensors 1-3 and current sensors 1 – 3 of the network are fed to the first input of the digital processing unit (DPU), which converts the mains voltage and mains current from coordinates *a*, *b*, *c* to coordinates α, β in accordance with the equation given in [4]. The third DPU input receives a voltage signal on the storage capacitor Cd to calculate a proportional value of the active switching power Pc. The DPU calculates the instantaneous values of active and inactive power. The components of active and reactive power allow to calculate the currents iFα and iFβ, which must be generated in the network by the voltage inverter to compensate the inactive components of instantaneous power.

The currents of the instantaneous values of the phase currents of the voltage inverter can be calculated from the currents iFα and iFβ in the coordinates α, β:

$$\begin{bmatrix} i_{Fa} \\ i_{Fb} \\ i_{Fc} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{F\alpha} \\ i_{F\beta} \end{bmatrix} \qquad (2)$$

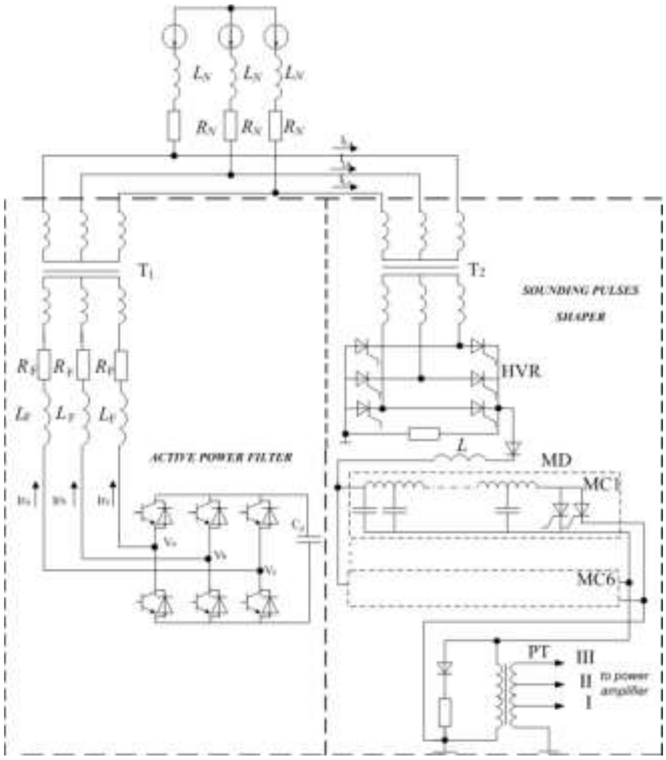


Fig. 4. The principle of connecting the APF and shaper to the mains

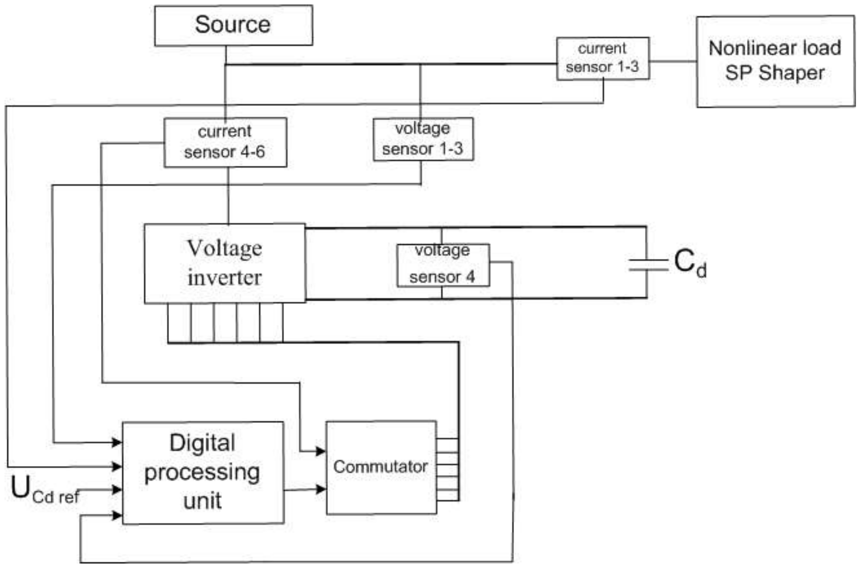


Fig. 5. The basic structure of the APF control system

The inverter currents from the DPU output are compared with the actual values of the phase currents of the inverter. Depending on the result of the comparison, the transistors of the corresponding arms of the voltage inverter are included.

Matlab-model of shunt active power filter with non-linear load - powerful sounding pulses shaper is shown in Fig. 6. Matlab-model includes voltage inverter - APF, the digital processing unit DPU, storage capacitive Cd, the pulses distribution block PDB and the load -

powerful sounding pulses shaper.

Using the developed Matlab-model, the following dependencies and characteristics can be investigated:

– energy characteristics of the shaper (reactive power, power factor in the node of connection of the shaper and APF to the mains);

– higher harmonics of current, which are generated by the shaper into the mains;

– the efficiency of the shaper when the power active filter is connected to the supply network;

– changes in reactive power and power factor in the node of power filter connection to the supply network, at different levels of reactive power consumption by the shaper.

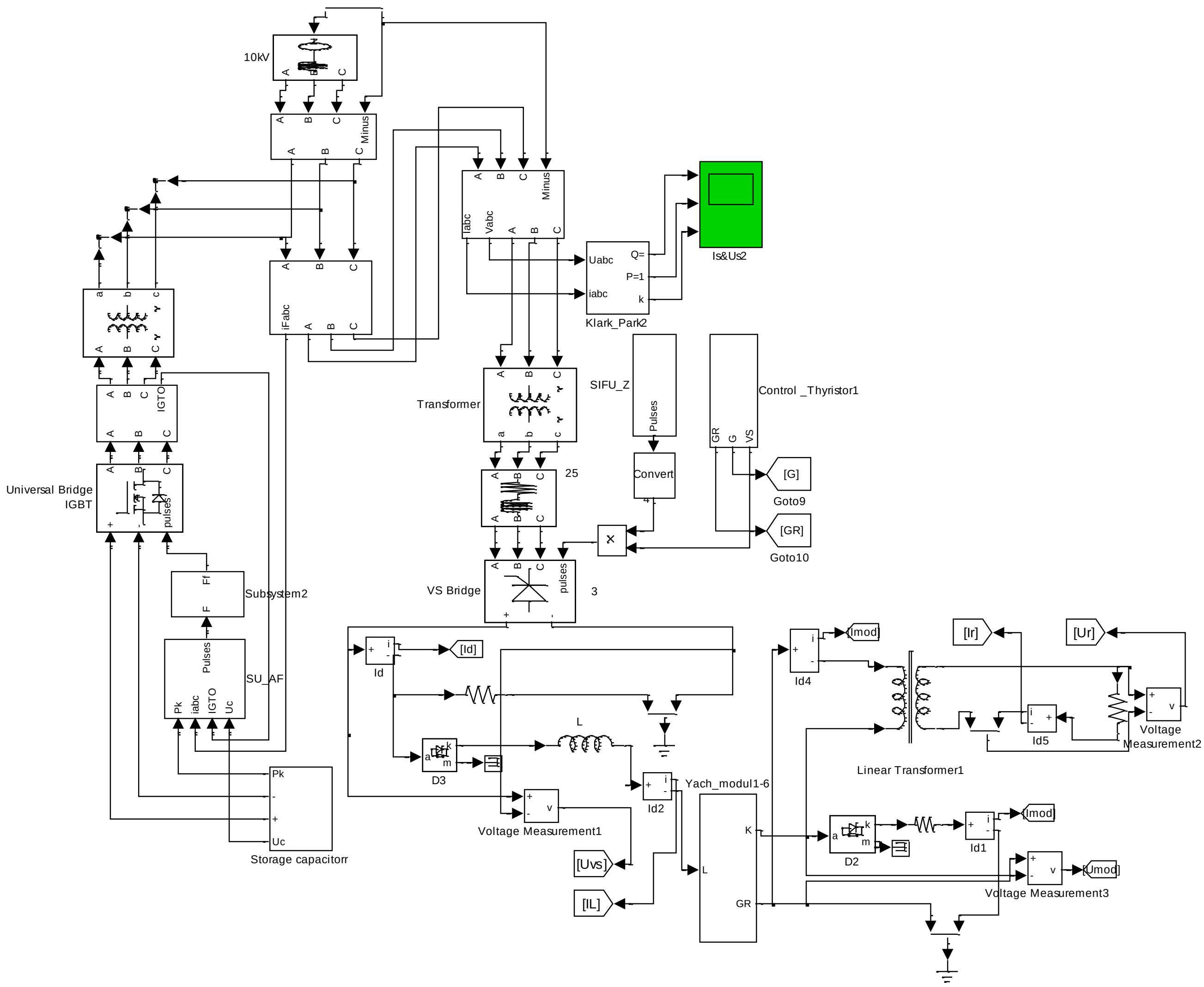


Fig. 6. Matlab-model of shunt active power filter with load

4. Simulation results

In Fig. 7 presents the obtained timing diagrams of transient processes when the APF is connected to the supply network. From top to bottom, changes of power factor *k*, reactive power *Q*, active power *P* and APF currents are shown.

Fig. 8 shows diagrams of reactive *Q* and active *P* power changes at the load side, and changes of the load power factor – *k*, at different reactive power levels consumed by the shaper.

Transient processes when changing the reactive power of the load in the APF and load connection node are shown in Fig. 9. The diagrams show that the reactive power *Q* remains compensated, and the power factor *k* is kept close to 1.

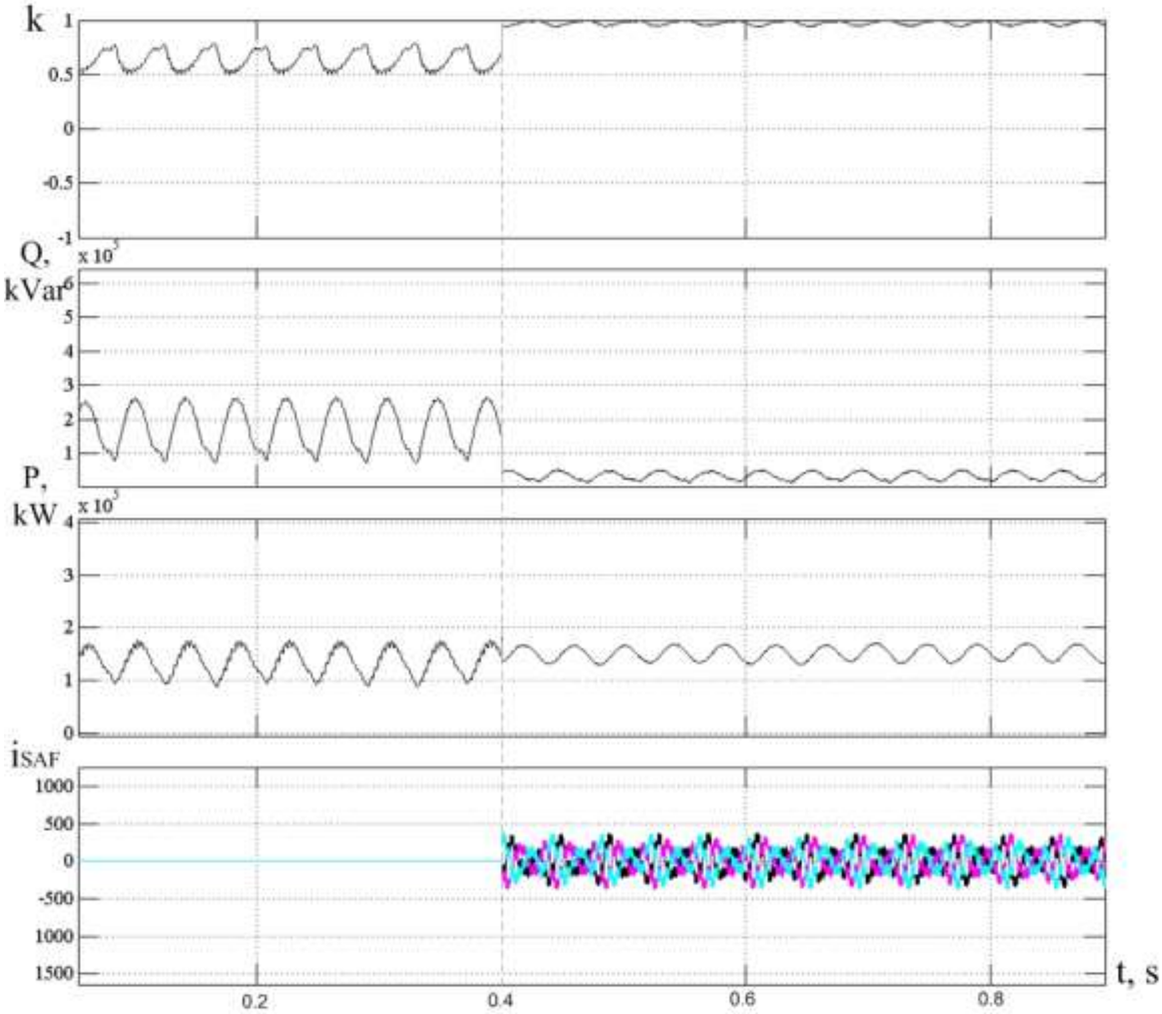


Fig. 7. Transient processes when the APF is connected to the supply network

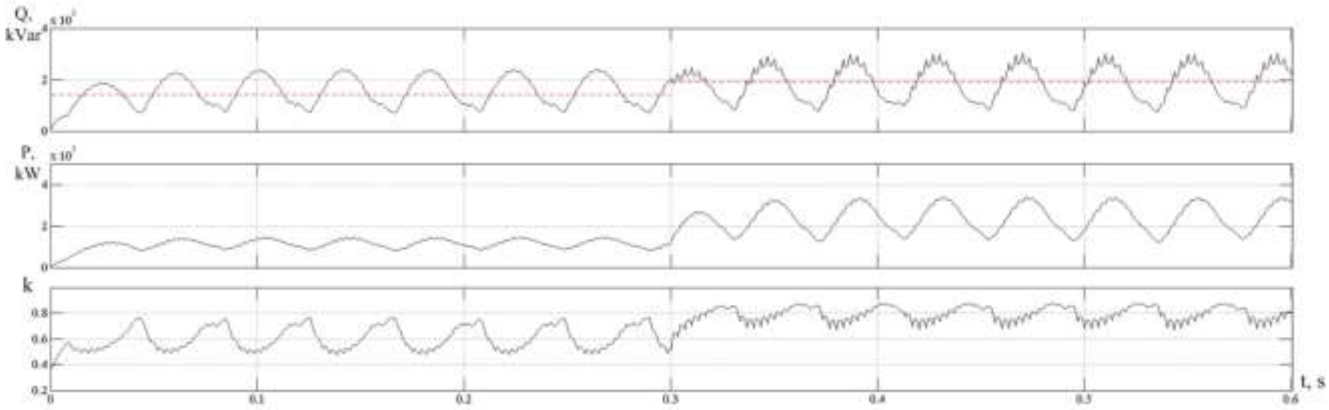


Fig. 8. Transient processes at different reactive power levels consumed by the shaper

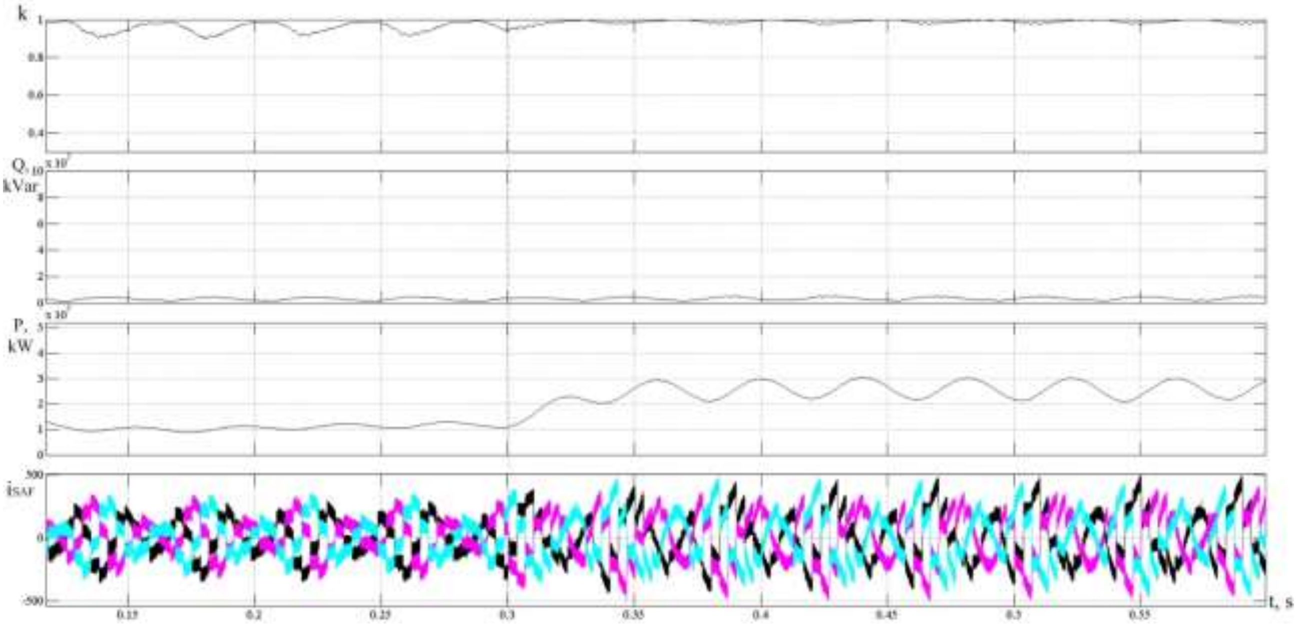


Fig. 9. Transient processes when changing the reactive power of the load in the APF and load connection node

5. Conclusions

The chosen topology of the APF power circuit showed good results. The results obtained during modeling using the developed Matlab-model of the system "APF-nonlinear load" confirmed the effectiveness of the selected APF scheme. When the APF is switched on to the power supply network, a slight decrease in the first harmonic of the current of the powerful sounding pulses shaper occurs, which has a positive effect on the efficiency of the shaper, causing the efficiency of compensation of reactive power consumed by the former from the supply network. The results obtained confirmed the possibility of using an active power filter in the mode of reactive power compensation of the supply network when solving the problems of improving the electromagnetic compatibility of powerful sounding pulses shapers with the supply network, reducing losses and increasing the reliability of the similar shapers.

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Силовий активний фільтр для компенсації реактивної потужності формувачів потужних зондуючих імпульсів

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Показана доцільність використання силового активного фільтру в режимі компенсації реактивної потужності мережі живлення для системи електроживлення формувача потужних зондуючих імпульсів Інституту іоносфери НАН та МОН України. Зроблено аналіз літератури, де показана ефективність вирішення проблеми компенсації реактивної потужності, фільтрації вищих гармонік мережі живлення з використанням активної фільтрації вищих гармонік струму або напруги із застосуванням додаткового джерела енергії для отримання компенсуючого сигналу, у вигляді струму або напруги. Виконано вибір силової схеми побудови САФ. В якості силового активного фільтру застосовується інвертор напруги на IGBT-транзисторах. Описано основні принципи роботи системи керування силовим активним фільтром, які засновані на p-q теорії потужності і передбачають розрахунок миттєвих значень струмів завдань для кожної фази трифазної системи електропостачання. Показана робота Matlab-моделі системи електроживлення формувача, наведені осцилограми основних енергетичних характеристик формувача. В результаті використання силового активного фільтру струм живильної мережі стає близьким до синусоїдального, а коефіцієнт потужності наближається до одиниці. Відзначено позитивний вплив на коефіцієнт корисної дії формувача при включенні силового активного фільтру в мережу живлення, що обумовлено ефективністю компенсації реактивної потужності, споживаної формувачем з мережі живлення. Представлені результати моделювання, зокрема, графіки зміни реактивної потужності в точці підключення силового активного фільтру до мережі живлення, при різних рівнях споживання реактивної потужності формувачем. Отримані результати підтвердили можливість використання силового активного фільтру в режимі компенсації реактивної потужності мережі живлення при вирішенні завдань поліпшення електромагнітної сумісності формувачів потужних зондуючих імпульсів з мережею живлення, зменшення втрат і збільшення надійності роботи формувачів.

Ключеві слова: *силовий активний фільтр, контроль реактивної потужності, системи керування*

Силовой активный фильтр для компенсации реактивной мощности формирователей мощных зондирующих импульсов

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Показана целесообразность использования силового активного фильтра в режиме компенсации реактивной мощности питающей сети для системы электропитания формирователя мощных зондирующих импульсов Института ионосферы НАН и МОН Украины. Произведен анализ литературы, где показана эффективность решения проблемы компенсации реактивной мощности, фильтрации высших гармоник сети питания с использованием активной фильтрации высших гармоник тока или напряжения с применением дополнительного источника энергии для получения компенсирующего сигнала, в виде тока или напряжения. Выполнен выбор силовой схемы построения САФ. В качестве силового активного фильтра применяется инвертор напряжения на IGBT-транзисторах. Описаны основные принципы работы системы управления силовым активным фильтром, которые основаны на p-q теории мощности и предусматривают расчет мгновенных значений токов заданий для каждой фазы трехфазной системы электроснабжения. Показана работа Matlab-модели системы электропитания формирователя, приведены осциллограммы основных энергетических характеристик формирователя. В результате использования силового активного фильтра ток питающей сети становится близким к синусоидальному, а коэффициент мощности стремится к единице. Отмечено положительное влияние на коэффициент полезного действия формирователя при включении силового активного фильтра в питающую сеть, что обусловлено эффективностью компенсации реактивной мощности, потребляемой формирователем из питающей сети. Представлены результаты моделирования, в частности, графики изменения реактивной мощности в точке подключения силового активного фильтра к питающей сети, при разных уровнях потребления реактивной мощности формирователем. Полученные результаты подтвердили возможность использования силового активного фильтра в режиме компенсации реактивной мощности питающей сети при решении задач улучшения электромагнитной совместимости формирователей мощных зондирующих импульсов с питающей сетью, уменьшения потерь и увеличения надежности работы формирователей.

Ключевые слова: *силовой активный фильтр, контроль реактивной мощности, системы управления*

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