UDC 621.314.12

O. Bialobrzheskyi, Cand. Sc. (Tech.), Assoc. Prof.,
A. Gladyr, Cand. Sc. (Tech.), Assoc. Prof.

Kremenchuk Mykhailo Ostrohradskyi National University, Kremenchuk, Ukraine, e-mail: seemal@kdu.edu.ua

INFLUENCE OF DISTORTION OF LOAD CURRENT ON PARAMETERS OF COMPONENTS OF THE PARALLEL POWER ACTIVE FILTER

О. В. Бялобржеський, канд. техн. наук, доц.,
А. І. Гладир, канд. техн. наук, доц.

Кременчуцький національний університет імені Михайла Остроградського, м. Кременчук, Україна, e-mail: seemal@kdu.edu.ua

ВПЛИВ ВИКРИВЛЕННЯ СТРУМУ НАВАНТАЖЕННЯ НА ПАРАМЕТРИ ЕЛЕМЕНТІВ ПАРАЛЕЛЬНОГО СИЛОВОГО АКТИВНОГО ФІЛЬТРУ

Purpose. Defining the relationship between the parameters of the energy storage components of the three-phase parallel power active filter and the character of current which is compensated.

Methodology. The methodology includes formation of the equivalent circuit for active power filter with the analysis of the distribution of the currents as well as their components in the branches by the principle of compensation. Analysis of time diagrams of the mode parameters by the character of the load current for the scheme which matches the equivalent circuit and was published in the previous papers. Moreover, the method involves the realization of experiments in order to determine the influence of the values of capacitor voltage and inductance of the inductive components on compensation quality of the load current by the electric power network current and the analytical determination of the power distortion influence on the average value and the deviation of the capacitor voltage of the power active filter. It also involves the justification of the rate of change of load current as a critical parameter using the experimental results. Analytical determination of the rate of change of load current of the power active filter taking into account its dependence on the delay angle for thyristor converter considering active component and instantaneous value of load current. Analysis of the rate of change of load current in the power active filter with several current delay angles of the thyristor converter and comparison of it with the transient current in the power active filter scheme using certain assumptions and taking into account the presence of energy storage components.

Findings. It is proved that the parameters of the circuit and the modes of the power active filter essentially depend on the rate of change of load current within a considered time interval. The results are based on the analysis of time diagrams for the mode parameters of the power parallel active filter used in the circuit with thyristor converter as a load.

Originality. Influence of the rate of change of load current on the mode parameters of the power active filter, and accordingly, on the parameters of the power circuit components which should additionally be taken into account for calculations by known methods is substantiated.

Practical value. It is determination of the influence of the rate of change of load current on parameters of components of the three-phase parallel power active power filter, which may be useful for their selection.

Keywords: *rate of change of load current, pulse control, total harmonic distortion (THD), current delay angle, angle of overlap, power distortion*

Introduction. Determination of rational parameters of storage power active filter is an important milestone that defines the technical characteristics of the device and the cost of its manufacture and use during product lifecycle. The analysis of single-phase power active filter provided reactive power compensation in the node of electric power network was executed in [1].

It was noted that the exchange of the components of the power caused by modulation occurs between the capacitive energy storage in the circuit with pulsating DC voltage and the inductive energy storage as a part of the filter in the load circuits on the side of AC voltage.

These high frequency components of voltage pulsations herewith take place in circuit between the capacitive and inductive elements during commutation of the converter switches.

These are the aspects which were laid in the criteria for selecting storage elements.

Analysis of the previous research. As a result of analysis of the three-phase power active filter during work on linear load [2] by the time and spectral diagrams that reflect the distribution of power and energy which is circulating in the electric power network between inductive and capacitive storages, facts indicated earlier were established exclusive of the mode parameters which form the exchange process of energy between the capacitor and the electric power network.

It is indicated for a three-phase parallel power active filter that a significant part of the energy is distributed between the phases of the electric power network and transistor converter of the filter.

A small part of the energy circulates between inductive and capacitor storages thereby providing a controllability mode.

There are methods of selection of electrical parameters of the elements for the power active filter [3], which have been successfully used for the linear loads which create harmonic (monoharmonic) currents in the lines of the electric power network.

As a result of a series of experimental research studies the insufficiency of these methodologies in the case of nonlinear loads, which create the polyharmonic current of the electric power network (grid) was determined.

Problem statement. Quality indicators of electric energy in node of connecting of the power active filter depend on the algorithm embedded in the control system and the parameters of energy storage elements of an active filter.

Existing methods for calculating these parameters for the case of the monoharmonic currents are insufficient for rational selection of circuit parameters for the case of the polyharmonic currents especially with strongly variable character.

Objectives of the article include definition of relationships of parameters of power storage elements of a three-phase parallel active power filter given the nature of the current during its compensation.

Presentation of the main research and explanation of scientific results. Let us consider the modes of operation of the parallel three-phase power active filter (*AF*) in the circuit (Fig. 1) which contains a power supply (*Grid*) and a three-phase bridge thyristor converter with active inductive load on the side of direct current as a consumer (*Load*).

The three-phase bridge thyristor converter is presented as a three-phase current source ($i_{k.ld}$) at the equivalent circuit (Fig. 1).

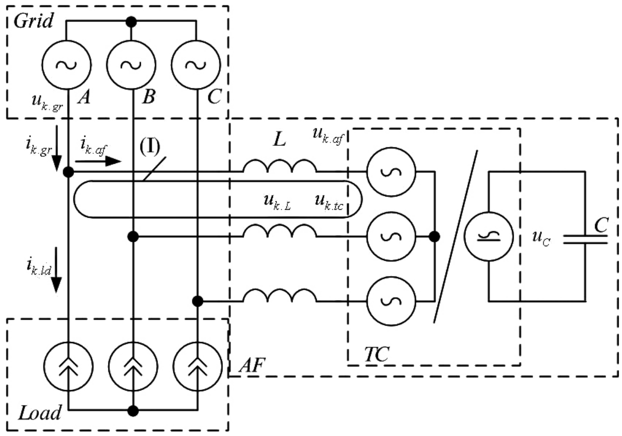

Fig. 1. Simplified equivalent circuit of the grid node with an active power filter

The voltage of the grid in phases ($k = A, B, C$) generally consists of the main harmonic $u^f_{k.gr}$, which varies with a period T, and higher harmonics $u^h_{k.gr}$

$$u_{k.gr} = u^f_{k.gr} + u^h_{k.gr}.$$

In the same way, the main harmonic $i^f_{k.gr}$ and higher harmonics $i^h_{k.gr}$ constitute the current of the grid

$$i_{k.gr} = i^f_{k.gr} + i^h_{k.gr}.$$

The voltage of the grid under the scheme (Fig. 1) acts on the load and on the active power filter herewith the load current $i_{k.ld}$ also generally contains components of the main harmonic $i^f_{k.ld}$ and higher harmonics $i^h_{k.ld}$

$$i_{k.ld} = i^f_{k.ld} + i^h_{k.ld}.$$

Thus, let us present the main current harmonic as two components: the first one matches the active power $i^f_{k.ld.p}$, and the second one matches the reactive power $i^f_{k.ld.q}$.

For analyzing the mode we should accept the assumption that the voltage does not contain the higher harmonics ($u^h_{k.gr} = 0$) in its composition. With this in mind the grid is a source of sinusoidal voltage with infinitely small internal resistance

$$u_{k.gr} = u^f_{k.gr}.$$

The current of the power active filter is determined by its destination – it is minimization (cut-off) of the higher harmonics of load current $i^h_{k.ld}$ and the main harmonic component which corresponds to the reactive power $i^f_{k.ld.q}$ [4]. Also it is necessary to keep in mind that the process of formation of active filter current $i_{k.af}$ during valve device commutation by performing relay regulation of the current or pulse width modulation is accompanied by appearance of the appropriate component of the current $i_{k.af}^{mod}$. So, the current equation of the power active filter can be written as

$$i_{k.af} = -i_{k.ld.q}^{f} - i_{k.ld}^{h} + i_{k.af}^{mod}.$$

The components of this current cause the appearance of the voltage on the inductive elements of the power active filter which is conditioned by reactive power $u_{k.L.q}^{f}$, higher harmonics of load current $u_{k.L}^{h}$ and modulating component of current

$$u_{k.L} = -u_{k.L.q}^{f} - u_{k.L}^{h} + u_{k.L}^{mod},$$

and (adding to load current) these components determine the grid current

$$\begin{aligned} i_{k.gr} &= i_{k.ld} + i_{k.af} = \\ &= i_{k.ld}^{f} + i_{k.ld}^{h} - i_{k.ld.q}^{f} - i_{k.ld}^{h} + i_{k.af}^{mod} = \\ &= i_{k.ld.p}^{f} + i_{k.af}^{mod} = i_{k.gr}^{f} + i_{k.gr}^{h}, \end{aligned}$$

that is with full compensation of reactive component of load current for the main harmonic and reduction of higher harmonics to zero, the grid current will have the main harmonic only that corresponds to the active power of load and higher harmonics caused by valve device commutation of the power active filter (Fig. 2).

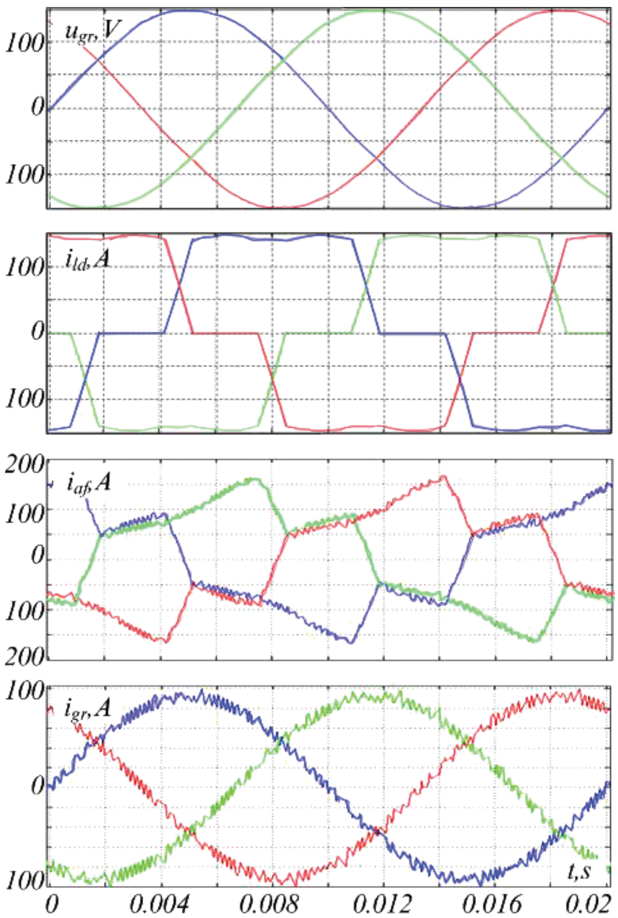

Fig. 2. Time diagrams of filter-compensating device in the system with a thyristor converter

The series of experimental research studies were executed for determination of the influence of the storage element parameters on the process of current formation of the power active filter.

Experiments were carried out for the effective value of grid voltage $U_{gr.rms} = 220\ V$ and calculating current of thyristor converter at an angle of 45° $I_{rat} = 120$ A, while the inductance of the input reactors $L = 0.0054\ H$; the capacitance of the capacitor $C = 20\ mF$; the volume of the capacitor $U_c = 2\ kV$; the mean value of switching frequency $f_{mod.a} = 5\ kHz$, determined according to the methodology [3].

Time diagrams for the first experiment are shown in Fig. 2. Experimental results (Table 1) were obtained by varying the values of the inductor and capacitor voltage.

As can be seen from Table 1 there is an ability to achieve total harmonic distortion THD for current that does not exceed 10 % in the case of the first and third experiments.

In the latter case, the inductance value decreases and this fact significantly affects the weight and dimensions performance. In addition, the voltage in the DC circuit decreases as well. It reduces the requirements for insulation properties of capacitors and transistors of the power converter. In the case of the last one this reduces its cost significantly.

Table 1

Element parameters and mode parameters of an active power filter

	$f_{mod.a}$, kHZ	U_c, kV	C, mF	L, mH	THD, %	$I_{gr.rms}$, A
Exp 1	10	2	20	5.4	5.69	92.07
Exp 2	5	1	20	5.4	22.83	116.2
Exp 3	10	1	20	2.7	9.5	95.95

Analysis of the diagrams in Fig. 3 shows the following. The quality of selection of rational element parameters of the power active filter stands out clearly in the conditions of the current load in case if it is close to rectangular shape with steep fronts of growth and decline, and high value of the rate of change of load current (Fig. 3, *a* and Fig. 4, *a*). Deflection of filter current is possible (Fig. 3, *a*) from the set point, which leads to harmonic distortion of grid current and increase in its effective value (Figs. 4, *b*, *c*) under the same conditions of control system configuration for the power active filter. It depends on the electrical parameters of the energy storage elements.

As opposed to the full compensation mode (Fig. 3, *e*) the existing distortions lead to constant changing of the mean value of the capacitor voltage per the period of the voltage pulsation (Figs. 3, *c, d*). This corresponds to the accumulation of electrical energy and the active component of the compensator current (Fig. 4, *d*).

As seen from the results of the experiments, it is possible to obtain close by the value indicators of the parameters of grid current with various combinations of inductance, capacitance and capacitor voltage: harmonic distortion factor, effective value of the main harmonic.

Thus known methodology [3] which was used during the previous calculation gives qualitative results of the calculation, provided that there are monoharmonic load currents and it requires clarification in case of polyharmonic currents.

In [5] they propose to take into account the distortion power T_c (decreasing of which is provided by device) in order to refine the calculation of capacitor capacity.

As a result, taking into account losses in the circuits of the converter of the power active filter P_A, the expression to determine the capacity of the capacitor with the certain mean value U_C and deviation of the capacitor voltage ΔU_C was obtained by the authors.

$$C = 2\frac{\int_0^{T/6}(T_c + P_A)dt}{\Delta U_C(\Delta U_C + 2U_C)}.$$

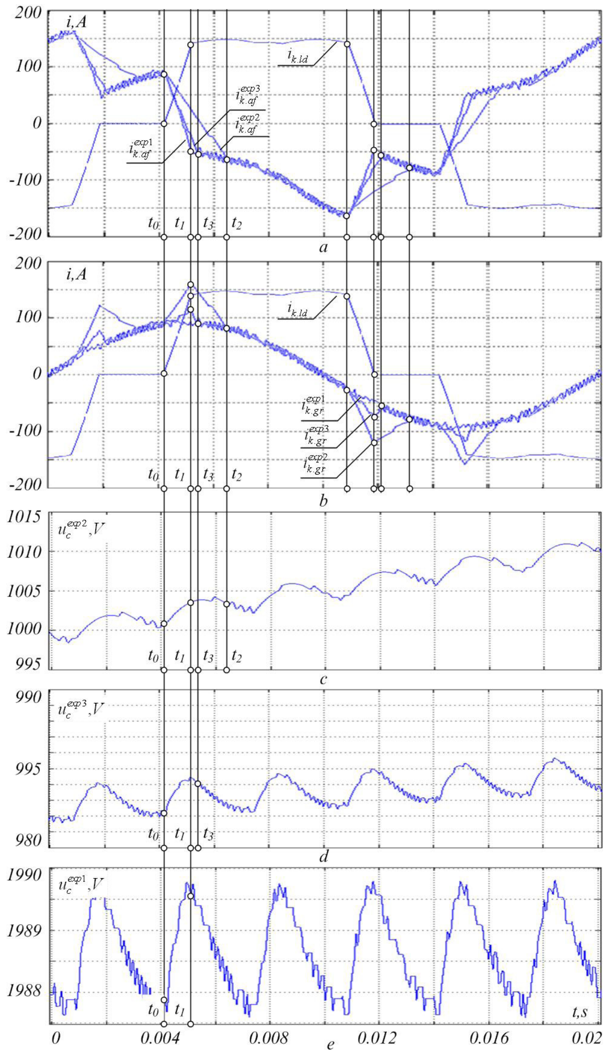

Fig. 3. Time diagram of mode parameters of the power active filter:

a – phase load current, phase compensator current; b – phase load current, phase grid current; c – capacitor voltage for the second experiment; d – capacitor voltage for the third experiment; e – capacitor voltage for the first experiment

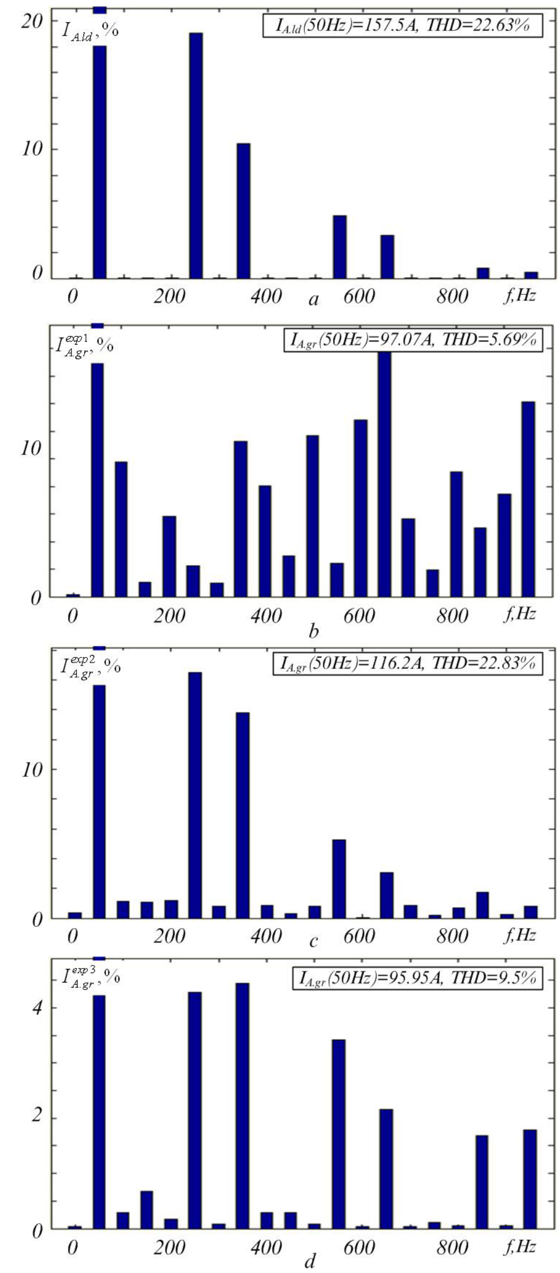

Fig. 4. Spectral current diagrams:

a – of load; b – of grid for the first experiment; c – of grid for the second experiment; d – of grid for the third experiment

Power distortion [6], which causes the change of voltage on the capacitor

$$T_c = S_{1.ld} \cdot THD_{I.ld}, \quad (1)$$

where $S_{1.ld}$ is full power of the first harmonic of nonlinear load; $THDI_{.ld}$ is the parameter the total harmonic distortion of load current.

Considering that the distortion power T_c is compensated by current of the active power filter, the energy on the interval $T/6 = 1/(6\omega)$, which is returned from capacitor C by changing the voltage ΔU_C should not be less than the energy caused by distortion power in this period.

The changing of the energy on the capacitor is caused by voltage fluctuation from the maximum $U_{C.\max}$ to minimum $U_{C.\min}$ value

$$\Delta W_C = \frac{C}{2}\left(U_{C.\max}^2 - U_{C.\min}^2\right), \qquad (2)$$

introducing similarly [1] parameter of voltage change in relation to the mean value

$$U_{C.0} = \frac{U_{C.\max} + U_{C.\min}}{2};$$

$$k_C = \frac{(U_{C.\max} - U_{C.\min})}{2U_{C.0}} = \frac{U_{C.\max}}{U_{C.0}} - 1 = 1 - \frac{U_{C.\min}}{U_{C.0}},$$

and change of energy

$$\Delta W_C = 2CU_{C.0}^2 k_C .$$

They determine the capacitance of the capacitive storage by equating (1) with (2) and taking into account the frequency of main harmonic pulsations of capacitor voltage

$$\frac{6S_{1.ld}THD_{I.ld}}{T} = 2CU_{C.0}^2 k_C \Rightarrow C = \frac{3S_{1.ld}THD_{I.ld}}{U_{C.0}^2 k_C T}.$$

Assuming that the voltage deviation is not greater than 10 % mean value, the capacitance of capacitor is

$$C = \frac{3S_1 THD_{I.ld}}{U_{C.0}^2 0.1T} = 30\frac{S_1 THD_{I.ld}}{U_{C.0}^2 T}.$$

It should be noted that the distortion power is an integral indicator and it cannot accordingly reflect the character of the distortion. It is the most important for quality assurance of the distortion elimination.

Let us consider the formation of current in power circuit (Fig. 1). The voltage drop on the inductive element L_k of the power active filter caused by the voltage of grid and the voltage of transistor converter, which in turn has a relationship to the voltage on the capacitor through switching function for the corresponding phase (ψ_k) [7]

$$L_k \frac{di_{k.af}}{dt} = u_{k.gr} - u_{k.tc} = u_{k.gr} - \psi_k u_C ,$$

while three transistors work at the same time in the scheme and the condition is fulfilled in the scheme without neutral conductor

$$i_{A.af} + i_{B.af} + i_{C.af} = 0 .$$

Thereby the voltage on the capacitor $U_{C.0}$ together with inductance and voltage of grid defines not only energy reserve of the capacitor but the maximum rate of change of current

$$\frac{di_{k.af}}{dt} = \frac{u_{k.gr} + \psi_{k.tc} u_C}{L_a}.$$

Considering conditions accepted in the study the current which should be compensated has the signal edges with high rate of change (~ 150 kA/sec – Fig. 3). The signal edge is caused by switching processes in grid circuits of the thyristor converter and is determined by the angle of overlap [8], which determines the appropriate rise time of current.

$$\gamma(\alpha, I_d) = \arccos\left(\cos\alpha - \frac{2I_d \omega L_{eq}}{\sqrt{3}U_{k.m}}\right) - \alpha \Rightarrow$$

$$\Rightarrow t_{sw} = \frac{1}{\omega}\left[\arccos\left(\cos\alpha - \frac{2I_d \omega L_{eq}}{\sqrt{3}U_{k.m}}\right) - \alpha\right],$$

where α is the current delay angle of the thyristor converter; I_d is the mean value of load current; L_{eq} is the equivalent inductance of grid circuit of the thyristor converter; ω is angular frequency of grid voltage; U_m is the amplitude of the grid voltage. The time of commutation in this case (Fig. 3, *a*) $t_{sw} = t_1 - t_0$. Taking the assumption that the load current of the thyristor converter after commutation is constant $I_d = const$, the rate of change of current within the interval of commutation is

$$\left.\frac{di_{k.ld}}{dt}\right|_{t_0} = \frac{I_d - 0}{t_1 - t_0} =$$

$$= I_d \omega \left[\arccos\left(\cos\alpha - \frac{2I_d \omega L_{eq}}{\sqrt{3}U_{k.m}}\right) - \alpha\right]^{-1}. \qquad (3)$$

Therefore, the desirable phase current of the power active filter, given the form of desirable grid current can be determined by the active component $i_{k.ld.}$ pof load current [9] and full load current

$$i_{k.af}^* = i_{k.ld.p} - i_{k.ld} = \sqrt{2}\frac{P_{k.ld}}{U_{k.ld}}\sin(\omega t + \psi_{k.u}) - i_{k.ld} ,$$

where $P_{k.ld}$ is the active power of phase load; $U_{k.ld}$ is the effective value of phase voltage of load; $\psi_{k.u}$ is the phase shift of phase voltage.

The rate of change of current of the active power filter is

$$\frac{di_{k.af}^*}{dt} = \sqrt{2}\omega\frac{P_{k.ld}}{U_{k.ld}}\cos(\omega t + \psi_{k.u}) - \frac{di_{k.ld}}{dt}. \qquad (4)$$

The mean value of load power (active power) for phase of grid of the three-phase bridge thyristor converter [8] is

$$P_{k.ld} = \frac{P_{ld}}{3} = \frac{\sqrt{6}U_{k.ld}I_d}{2\pi}\cos\alpha . \qquad (5)$$

Taking the assumption that the phase shift of phase voltage $\psi_{k.u} = 0$, the rate of change of current of the active power filter within the interval of commutation of valves (α) taking into account expressions (3–5) is

$$\frac{di^*_{k.af}}{dt}(\alpha) = I_d\omega\frac{\sqrt{3}}{\pi}\cos^2\alpha + \\ +I_d\omega\left[\arccos\left(\cos\alpha - \frac{2I_d\omega L_{eq}}{\sqrt{6}U_{k.ld}}\right) - \alpha\right]^{-1}. \quad (6)$$

In this case as described previously (Fig. 3) the number of the switchings per one period of grid voltage is six. If we consider the interval of commutation of valves for the thyristor converter (t_0–t_1) (Fig. 3, *b*) then the rate of change of current of phase with the valve that is being closed differs by the sign from the rate of change of current of phase with the valve that is being opened, remaining the same in value. In this time interval the current in the third phase varies slightly (Fig. 2) and is accepted as constant. Let us consider the relationship of mode parameters for phases A and B under the conditions that current delay angles are acted in accordance with Table 2, taking the assumption that the amplitude of grid voltage of phase A is

$$U_{m.A} = \sqrt{2}U_{A.ld} = \frac{1}{\sqrt{3}}U_{m.AB}.$$

Using the initial data in which the experiments were carried out: L_{eq} = 0.0036 *H*; P_{ld} = *14 kWt*; $U_{AB.RMS}$ = *=220 V*; I_d = 150 *A*, L_k = 0.0054 *H*, $L_a = L_{eq} + L_k$ let us define numerical values of expressions in Table 2 and summarize them to Table 3.

Table 2

The rate of change of current and interphase voltage depending on the current delay angle of the thyristor converter

№	α	$\frac{di^*_{A.af}}{dt}(\alpha)$	$U_{AB.gr}(\alpha)$
1	0	$I_d\omega\frac{3\sqrt{3}}{4\pi} + I_d\omega\left[\arccos\left(1 - \frac{2I_d\omega L_{eq}}{\sqrt{3}U_{m.A}}\right)\right]^{-1}$	0
2	$\frac{\pi}{3}$	$I_d\omega\left[\arccos\left(\frac{1}{2} - \frac{2I_d\omega L_{eq}}{\sqrt{3}U_{m.A}}\right) - \frac{\pi}{3}\right]^{-1}$	$\frac{3}{2}U_{m.A} = \frac{\sqrt{3}}{2}U_{m.AB}$
3	$\frac{\pi}{2}$	$I_d\omega\frac{\sqrt{3}}{4\pi} + I_d\omega\left[\arccos\left(-\frac{2I_d\omega L_{eq}}{\sqrt{3}U_{m.A}}\right) - \frac{\pi}{2}\right]^{-1}$	$\sqrt{3}U_{m.A} = U_{m.AB}$
4	$\frac{5\pi}{6}$	$I_d\omega\frac{\sqrt{3}}{\pi} + I_d\omega\left[\arccos\left(-\frac{\sqrt{3}}{2} - \frac{2I_d\omega L_{eq}}{\sqrt{3}U_{m.A}}\right) - \frac{5\pi}{6}\right]^{-1}$	$\frac{\sqrt{3}}{2}U_{m.A} = \frac{1}{2}U_{m.AB}$

Table 3

The results of numerical calculation of mode parameters for the active power filter

№	α, *rad*	$\frac{di^*_{A.af}}{dt}(\alpha)$, *A/s*	$U_{AB.gr}(\alpha)$, *V*	$2L_A\frac{di^*_{k.af}}{dt}(\alpha)$, *V*	$U_{AB.gr}(\alpha) + 2L_A\frac{di^*_{k.af}}{dt}(\alpha)$, *V*
1	0	62030	0	669.92	669.92
2	$\frac{\pi}{3}$	72100	466.68	778.68	1245.36
3	$\frac{\pi}{2}$	69200	538.89	747.36	1286.25
4	$\frac{5\pi}{6}$	57420	269.44	620.14	889.58

Thus, in this case the capacitor voltage should be calculated for the current delay angle $\alpha = \frac{\pi}{2}$ by expression

$$U_C \ge \sqrt{3} U_{m.A} \sin\left(\frac{\pi}{2}\right) +$$
$$+2L_A \left[I_d \omega \frac{\sqrt{3}}{4\pi} + I_d \omega \left[\arccos\left(-\frac{2 I_d \omega L_{eq}}{\sqrt{3} U_{m.A}} \right) - \frac{\pi}{2} \right]^{-1} \right].$$

Assuming the necessity of forming the line current using the active power filter with the given rate of change $\frac{di^{ref}_{k.af}}{dt}$, let us consider the process of changing the current of scheme (Fig. 1) in the equivalent circuit (I), taking the assumption that two valves of the transistor converter are turned on and the capacitor is fully put into circuit.

In general, the transient component of circuit current is

$$i^*_{A.af} = -\frac{1}{\omega} e^{-\beta t} \left(\left(I_0 \beta + C U_0 \beta^2 + C U_0 \omega^2 \right) \sin(\omega t) - \right.$$
$$\left. - I_0 \omega \cos(\omega t) \right), \qquad (7)$$

where $\beta = \frac{r_f}{2L_\Sigma}$; $\omega_0 = \frac{1}{\sqrt{L_\Sigma C}}$; $\omega = \sqrt{\omega_0^2 - \beta^2}$; r_f is the active resistance of circuit; $L_\Sigma = 2L_k$ is the total inductance of circuit; C is capacitance of the capacitor. Thus there are initial conditions (Fig. 3, *a*) for the point t_{0-}, $u_c\big|_{t=t_0} = U_0 \ne 0$ current $i_{a.af}\big|_{t=t_0} = I_0 = 0$.

The time graph of the transition current is shown in Fig. 5 for the previously mentioned parameters of circuit. The limits of deviations of current ($\pm HB$) of the setpoint caused by the configuration of control system and, in the this case, constitute $HB = 0.1 I_{rat}$. Let us determine the time t_1 (Fig. 5) which corresponds to intersection of the instantaneous current $i^{ref}_{A.af}$ and line $i^{ref}_{A.af} - HB$ (Fig. 5). According to formula (4) for $t = t_0$,

$$\left.\frac{di^*_{A.af}}{dt}\right|_{t=t_0} = \beta e^{-\beta t_0} \times$$
$$\times \left(\left(I_0 \beta + C U_0 \beta^2 + C U_0 \omega^2 \right) \cos(\omega t_0) + I_0 \omega \sin(\omega t_0) \right). \quad (8)$$

Assuming that the transient begins at the $t_0 = 0$, and given the fact that the rate of change of current of the filter should be equal to the rate of change of set current

$$\left.\frac{di^*_{A.af}}{dt}\right|_{t=0} = \frac{di^{ref}_{A.af}}{dt},$$

equating the right sides of formulas (3) and (5) we will obtain the expression

$$\beta \left(I_0 \beta + C U_0 \beta^2 + C U_0 \omega^2 \right) = I_d \omega \frac{\sqrt{3}}{\pi} \cos^2 \alpha +$$
$$+ I_d \omega \left[\arccos\left(\cos\alpha - \frac{2 I_d \omega L_{eq}}{\sqrt{6} U_{k.ld}} \right) - \alpha \right]^{-1},$$

that connects circuit and mode parameters of the active filter with circuit and mode parameters of load current.

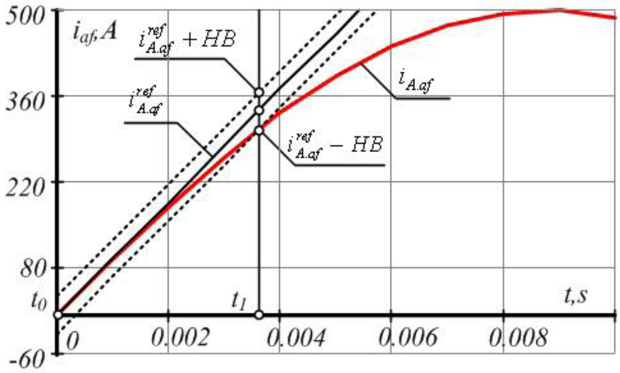

Fig. 5. Time dependence of transient current and determination of its deviations from the set value on the HB value

The point of intersection of the instantaneous current with line $i^{ref}_{A.af} - HB$ (Fig. 5) is determined by the equation

$$\left| i^*_{A.af} - i^{ref}_{A.af} \right| = HB,$$

or

$$\left| -\frac{1}{\omega} e^{-\beta t} \left(\left(I_0 \beta + C U_0 \beta^2 + C U_0 \omega^2 \right) \sin(\omega t) - \right. \right.$$
$$\left. \left. - I_0 \omega \cos(\omega t) \right) - at \right| = HB.$$

The solution of this equation finds the time t_1 during which the circuit can provide the level of deviation not more than 10 % of the set current of active power filter. So the relationship is determined for parameters of capacitance (C), inductance (L_k) and voltage of the capacitor (U_{c0}) of commutating current of thyristor load transducer and the width of the hysteresis loop (HB) of the relay current regulator.

In evaluating the rate of change of current and the time of its implementation it is necessary to consider (in addition to the above parameters) the influence of the commutation process associated with increasing of switching frequency.

The conductivity of the main circuit increases with increasing transistor switching frequency. It causes increase in the loss of voltage and power. As a result, the overload capacity of element by the load current will be decreased, for example, as shown in Fig. 6 [10].

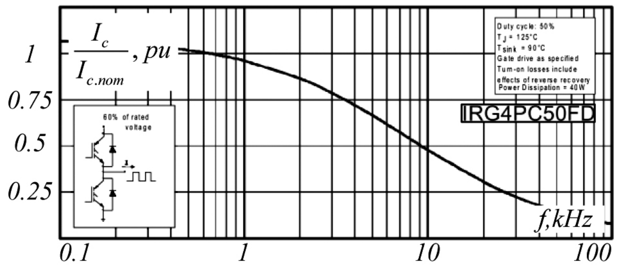

Fig. 6. The dependence of the collector current of the transistor switch IRG4PC50FD on the commutation frequency

There should be noted essential influence of current modulation of the transistor converter of the power active filter on the values of total harmonic distortion for voltage at the point of connection, taking into account inductive resistance of line as shown in [1].

Conclusions and recommendations for further research. By the experimental research it was determined that the applying of known methods for calculating the parameters of the power circuit active filter in case of compensation of load currents with considerable distortion of shape, including grid current of the three-phase bridge thyristor converter is insufficient.

Considering the procedure for calculating capacity of the capacitor in DC circuits of the active power filter there was noticed insufficiency of consideration of power distortion because it is an integral factor and actually summarizes current distortion not reflecting their character.

Using the active power filter for loads with sharply variable character of current without energy storage, as stated in some works, is not possible in the absence of supply of energy which is necessary to compensate the differential load current that is provided by the capacitor with corresponding parameters.

The relationship between mode parameter of the three-phase bridge thyristor converter as a load and mode and scheme parameters of the active power filter was defined analytically from the standpoint of forming the set value of differential current of active power filter.

Subsequent studies will be performed in the direction of solving equations presented in this paper, comparing the known parameters of load mode of grid with the values of parameters of the power active filter: inductance, capacitance, voltage on capacitor.

References.

1. Bialobrzeski, O. V. and Vlasenco, R. V., 2015. Interrelation of electric power parameters the mode a single-phase active filter with parameters of attaching stores. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu,* 4, pp. 79–84.

2. Vlasenko, R. V. and Bialobrzeski, O. V., 2014. Analysis of energy processes in the three-phase power active filter using spectral modeling. *Electronics and Electricity*, 1, pp. 12–18.

3. Zakis, J., Rankis, I. and Zhiravetska, A., 2007. Comparison of flexible systems for compensation of reactive power. *Power & Electrical Engineering,* Issue 20, pp. 225–233.

4. A Akagi, H., Watanabe, E. H. and Aredes, M., 2007. *Instantaneous Power Theory and Applications to Power Conditioning*. New York: Wiley - IEEE Press.

5. Plekhov, A. S., Titov, D. Yu. and Chernov, E. A., 2014. Calculation of the capacitance of the capacitor on the DC link active harmonic filter. *Electronic scientific journal Engineering Journal of Don*. [online]. Available at: <http://ivdon.ru/en/magazine/archive/n1y2014/2243> [Accessed 26 July 2016].

6. Institute of Electrical and Electronics Engineers, IEEE Std 1459-2010: *IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions,* Piscataway, USA, March 2010.

7. Schreiner, R. T., Medvedev, A. V. and Poliakov, V. N., 2016. Electromechanical resources adjustable-frequency synchronous drive in continuous periodic modes. *Electrical engineering*, 6, pp. 25–31.

8. Zinoviev, G. S., 2012. *The power electronics bases*. Moscow: Urait Publishing House.

9. Manish, Kr. Singh and Jayanti Chaudhary, 2014. Fryze current controller based active power filter. *IFAC Proceedings Volumes, 3rd International Conference on Advances in Control and Optimization of Dynamical Systems*, 47(1), pp. 794–800.

10. Infineon Technologies, 2016. Insulated gate bipolar transistor with ultrafast soft recovery diode IRG4PC50FD [online]. Available at: <http://www.infineon.com/dgdl/irg4pc50fdpbf.pdf?fileId=5546d462533600a401535644490122e4> [Accessed 26 July 2016].

Мета. Визначення зв’язку параметрів накопичувальних елементів трифазного паралельного силового активного фільтру з характером струму, що підлягає компенсації.

Методика. Включає складання схеми заміщення силового активного фільтру з аналізом розподілу струмів у гілках та їх складових за принципом компенсації. Аналіз часових діаграм параметрів режиму схеми, що відповідає схемі заміщення та досліджена в раніше опублікованих роботах, за характером струму навантаження. Проведення експериментів для виявлення впливу значення напруги конденсатора й величини індуктивності на якість компенсації струму навантаження за струмом мережі. Аналітичне визначення впливу потужності спотворення на середнє значення й відхилення напруги конденсатора силового активного фільтру. Обґрунтування, на підставі результатів експериментів, в якості критичного параметру диференціалу струму навантаження. Аналітичне визначення диференціалу струму силового активного фільтру з урахуванням активної складової струму й миттєвого струму навантаження – тиристорного перетворювача, у залежності від кута керування останнім. Аналіз диференціалу струму силового активного фільтру для декількох кутів керування тиристорним перетворювачем навантаження та порівняння його, за певних припущень, з перехідним струмом у схемі силового активного фільтру, що може бути забезпечений накопичувальними елементами фільтру.

Результати. На підставі аналізу часових діаграм параметрів режиму силового паралельного активного фільтру, застосовуваного у схемі навантаження з тиристорним перетворювачем, доведено, що параметри схеми й режиму силового активного фільтру істотно залежать від швидкості зміни струму у часі.

Наукова новизна. Обґрунтовано вплив швидкості зміни струму навантаження на режимні параметри силового активного фільтру та, відповідно, на параметри елементів силової схеми останнього, що необхідно додатково враховувати при їх розрахунках за відомими методиками.

Практична значимість. Полягає у визначенні впливу швидкості зміни струму навантаження на параметри елементів силової частини трифазного паралельного силового активного фільтру, що може бути використано при їх виборі.

Ключові слова: *диференціал струму, імпульсне управління, коефіцієнт загальних нелінійних спотворень, кут управління, кут комутації, потужність спотворення*

Цель. Определение связи параметров накопительных элементов трехфазного параллельного силового активного фильтра с характером тока, подлежащего компенсации.

Методика. Включает составление схемы замещения силового активного фильтра с анализом распределения токов в ветвях и их составляющих по принципу компенсации. Анализ временных диаграмм параметров режима схемы, соответствующей схеме замещения и исследованной в ранее опубликованных работах, по характеру тока нагрузки. Проведение экспериментов для выявления влияния значения напряжения конденсатора и величины индуктивности на качество компенсации тока нагрузки по току сети. Аналитическое определение влияния мощности искажения на среднее значение и отклонение напряжения конденсатора силового активного фильтра. Обоснование, на основании результатов экспериментов, в качестве критического параметра дифференциала тока нагрузки. Аналитическое определение дифференциала тока силового активного фильтра с учетом активной составляющей тока и мгновенного тока нагрузки – тиристорного преобразователя, в зависимости от угла управления последним. Анализ дифференциала тока силового активного фильтра для нескольких углов управления тиристорным преобразователем нагрузки и сравнение его, при определенных допущениях, с переходным током в схеме силового активного фильтра, который может быть обеспечен накопительными элементами фильтра.

Результаты. На основании анализа временных диаграмм параметров режима силового параллельного активного фильтра, используемого в схеме нагрузки с тиристорным преобразователем, доказано, что параметры схемы и режима силового активного фильтра существенно зависят от скорости изменения тока во времени.

Научная новизна. Обосновано влияние скорости изменения тока нагрузки на режимные параметры трехфазного параллельного силового активного фильтра и, соответственно, на параметры элементов силовой схемы последнего, что необходимо дополнительно учитывать при их расчетах по известным методикам.

Практическая значимость. Заключается в определении влияния скорости изменения тока нагрузки на параметры элементов силовой части трехфазного параллельного силового активного фильтра, что может быть использовано при их выборе.

Ключевые слова: *дифференциал тока, импульсное управление, коэффициент суммарных нелинейных искажений, угол управления, угол коммутации, мощность искажения*

Рекомендовано до публікації докт. техн. наук Д. Й. Родькіним. Дата надходження рукопису 21.09.16.