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Operational Regimes of Input Filters

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Introduction

One of the main elements of electric trains of an alternating current with the motor of an alternating current is entrance *LC* filter [1, 2], which should smooth the current consumed from the rectifier. This unit is necessary also in work with pulse regulators [3], which adjust a voltage of traction motors of a direct current. If the current was ideally smoothed, then from a network of an alternating current
the one of the rectangular form i_1 (Fig. 1.) would be consumed.

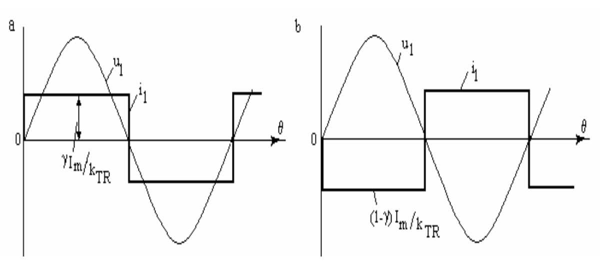

Fig. 1. Idealized form of a network current in traction *(a)* and brake *(b)* operation modes

Effective value of this alternating current coincides with amplitude of a current, that is,

$$I_1 = I_L / k_{TR}, \tag{1}$$

where I_L - an average current of a reactor of filter *L*. As the current coincides on a phase with a voltage of a network, the total consumed power

$$S_1 = I_1 \cdot U_1, \tag{2}$$

and active power

$$P_1 = I_L \cdot U_m, \tag{3}$$

where U_m=0.9U_1/k_{TR} , k_{TR} – transformation coefficient of entrance transformer. Then the power factor is determined as $\chi = \frac{P_1}{S_1} = 0.9$. This power factor practically is constant and enough high, that is the big advantage of this system. Effective value of the fundamental harmonic of a current of such form is determined as

$$I_{1(1)} = 0.9 I_1, \tag{4}$$

and effective values of all other odd harmonics will be inversely proportional to numbers of harmonics *nh* = 3, 5, 7, 9.... It means, that the network current has constant harmonious structure with constant number of the relation of amplitudes of harmonics.

However, it is really difficult to achieve completely smoothed current of a reactor, as pulsations of the rectified voltage of the single-phase bridge rectifier are very big (Fig. 2) and their frequency is very small - 100Hz.

In connection with that a real processes in the filter differ from idealized, it is necessary to lead the specified calculation of processes of the filter. It too is a problem of this work.

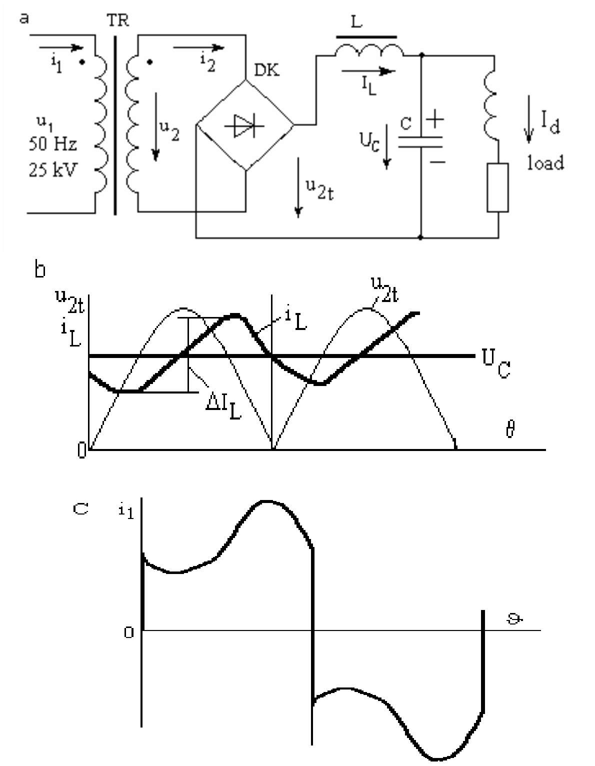

Fig. 2. Connection of the entrance filter to the network transformer: *a)* the circuit; *b*) the form of a current of a reactor of the filter i_L at work with rectified voltage u_{2t}; *c*) the real form of a network current

Processes in the filter

Processes in the filter with the big capacitance of the capacitor can be described using the following differential equation :

$$L\frac{di}{dt} = U_m|\sin\omega t| - 0.9\frac{U_m}{\sqrt{2}}, \quad (5)$$

where last member describes an average meaning U_c of voltage of the capacitor. Solving this equation, we receive expression for a current of a reactor

$$i_L = -\frac{U_m}{\omega L}\cos\omega t - \frac{0.9U_m}{\sqrt{2}\cdot L}t + A, \quad (6)$$

where A – is an initial condition.

If to accept, that at t=0 current $i = I_d$ it can be received that $A = I_d + \frac{0.9U}{\omega L}$ and changing of an instant current is described as

$$i_L = \frac{\sqrt{2}U}{\omega L}(1-\cos\omega t) + I_d - \frac{0.9U}{L}t. \quad (7)$$

To find the minimal and maximal values of a current, it is necessary to find the moments of time in which value of the rectified voltage u_{2t} coincides with a voltage of capacitor U_C. If frequency of a network is 50 Hz it occurs at the moment of time

$$t_1 = \frac{1}{\omega}\arcsin\frac{U_C}{U_m}. \quad (8)$$

At ω = 314 1/s and $U_C = 0.9U_m/\sqrt{2}$ this moment of time is 2.2 ms. The second crossing will be at 10 – 2.2 = 7.8 ms. Taking into account this time in the equation of a current, we receive expressions for calculation of the minimal and maximal instantaneously current:

$$I_{\min} = \frac{\sqrt{2}U}{314L}0.229 + I_d - \frac{0.9U}{L}2.2\cdot 10^{-3}; \quad (9)$$

$$I_{\max} = \frac{\sqrt{2}U}{314L}1.77 + I_d - \frac{0.9U}{L}7.8\cdot 10^{-3}. \quad (10)$$

Observing the received expressions, a full pulsation of a current of a reactor

$$\Delta I_L = \frac{\sqrt{2}U}{314L}1.54 - \frac{0.9U}{L}5.6\cdot 10^{-3}. \quad (11)$$

Instantaneous values of current of the capacitor can be described as

$$i_C = i_L - I_d = \frac{\sqrt{2}U}{\omega L}(1-\cos\omega t) - \frac{0.9U}{L}t. \quad (12)$$

Applying this expression, it is possible to calculate a voltage of the capacitor as

$$u_C = \frac{1}{C}\int i_C dt + B =$$

$$= \frac{\sqrt{2}U}{\omega LC}\int(1-\cos\omega t)dt - \frac{0.9U}{LC}\int t dt + B$$

or

$$u_C = \frac{\sqrt{2}U}{\omega LC}(t - \frac{\sin\omega t}{\omega}) - \frac{0.45U}{LC}\cdot t^2 + B.$$

If approximately to accept, that at t = 0 voltage of the capacitor u_C = $U_{Cmax,}$ then it can be received $B = U_{C\max}$ and also a curve of change of an instant voltage is described as

$$u_C = \frac{\sqrt{2}U}{\omega LC}(t - \frac{\sin\omega t}{\omega}) - \frac{0,45U}{LC}\cdot t^2 + U_{C\max}. \quad (13)$$

Value of the minimal voltage approximately will be at the moment of time $t = \frac{\pi}{2\omega}$ and then the minimal voltage stands as

$$U_{C\min} = U_{C\max} + \frac{U}{\omega^2 LC}[\frac{\pi}{\sqrt{2}} - \sqrt{2} - \frac{0.9\pi^2}{8}]. \quad (14)$$

Then the full pulsation of a voltage of the capacitor stands as

$$\Delta U_C = \frac{U}{\omega^2 LC}[\frac{\pi}{\sqrt{2}} - \sqrt{2} - \frac{0.9\pi^2}{8}] = \frac{0.304U}{\omega^2 LC}. \quad (15)$$

To check up the received expressions, computer modeling was carried out. Computer modeling is carried out at a network's voltage 600 V and various values *L, C* (look Fig. 3). As we can see, pulsations of an entrance current mainly depend on inductance of a reactor. The inductance is lesser, the pulsation of a current is more. If to limit pulsations of a current of a reactor at a level of 10 % from a current of loading then value of inductance in the consent with expression (11) is defined as

$$L = \frac{0.00189U}{0.1I_d}. \quad (16)$$

As we see from the data of computer modeling (see the table) and from data on Fig. 3, concurrence between ranges of pulsations of a current are on an allowable technological level. A mistake of pulsations of a voltage is much more, it is especial at the big values of capacitance. However, it is possible to accept, that the received calculation expressions can be applied in practice.

Table 1. The comparative table of results of computer modeling and the calculation data

Parameters L, C	The calculation data		Results of computer modeling	
	ΔI, A	ΔU, V	ΔI, A	ΔU, V
0,003; 0,003	379,27	205,55	543,86	283,1
0,01; 0,01	113,76	18,5	125,97	32,31
0,05; 0,05	22,75	0,74	25,57	5,6

Choice of parameters

To have an opportunity to choose inductance of a reactor depending on allowable pulsations of a current, on Fig. 4 the curve $L = f(\Delta I_L / I_d)$ is represented. As we see, the more is allowable pulsation of a current, then can be inductance of a reactor lesser. Increasing relation U/I_d, necessary inductance is increased also. For a practical choice it is necessary to accept value I_d maximum big and ΔI_L to accept as 2 minimal values I_d that provides a continuity of a current in a reactor.

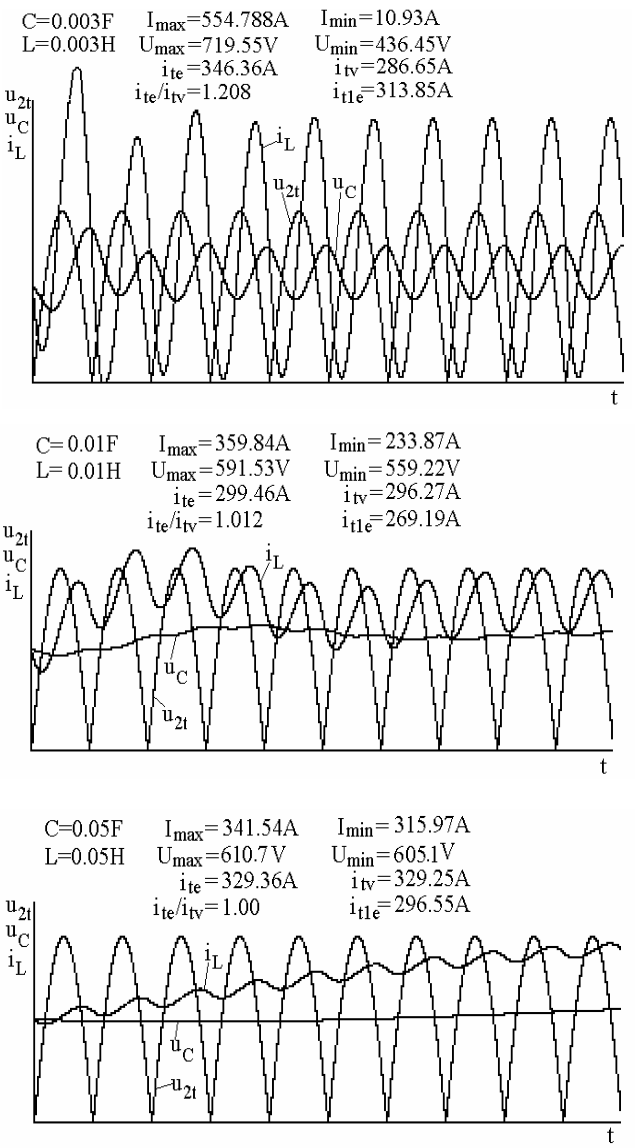

Fig. 3. Results of computer modeling: time diagrams of instant values of a current i_L of a reactor of the filter and a voltage of the capacitor u_C of the filter at various values of L and C; the maximal and minimal in stationary mode instant values respectively I_{max} ,U_{max} and I_{min} and U_{min}; an effective i_{te} and average i_{tv} values of an input current of a reactor, and also the first harmonic i_{t1e} of an input current of a rectifier

As we see from the diagrams on Fig.4, when the relation of pulsations is lesser, the greater inductance of the reactor needs to be applied. Practically, if minimal I_d makes 0.05 from maximal it is necessary to apply the relation 0.1, and at the relation of a voltage and the maximal current equal two, it is necessary to apply a reactor with inductance close to 40 mH. It is important to estimate weight of this reactor which needs to be defined on a loading current, which makes a part from the maximal current. Calculations can be conducted on considered in [4] connections of a two-rod reactor with two coils.

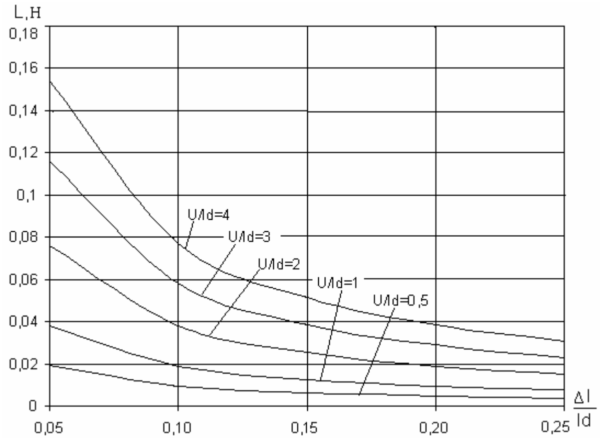

Fig. 4. Curve $L = f(\Delta I_L / I_d)$ at various values U/I_d

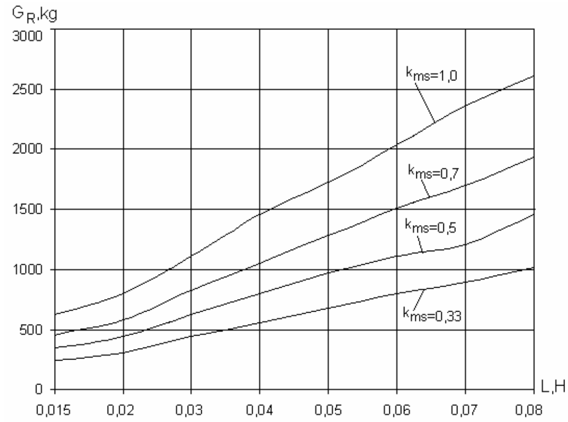

Fig. 5. Curves $G_R = f(L)$ at various values k_{ms} (results of computer modeling), designed at the maximal current 300 A

On Fig. 5. such designed weights of reactors are represented depending on necessary inductance L at the maximal current 300 A and relation of the rated loading current to the maximal one as factor k_{ms}. Thus

$$k_{ms} = I_N / I_d. \tag{17}$$

As we see from Fig. 5, the L is more, the weight of a reactor and accordingly dimensions are more. Thus dimensions and weight grow, if the factor of relations grows too. Really for the filter, this relation should be close 0.5 and then, for example, at necessary inductance 0.04 H the weight of a reactor can reach 700-1000 kg. As we see, weight of a reactor is impressive, and its volume reaches 0.1 m^3 .

Influence on a network

The form of a network current with the filter on an input is represented on Fig. 2. *c*. It is important to investigate harmonious structure of this current. On Fig. 6 effective values of the maximum harmonics (nh = 3, 5, 7, 9, 11) are represented depending on inductance L at C = 0.01 F. Figure is executed according to computer modeling at a current of loading 300 A.

According to computer modeling we can define the factor of the total harmonics distortion of current THD depending on inductance L. Thus

$$THD = \frac{\sqrt{I_{(3)}^2 + I_{(5)}^2 + I_{(7)}^2 + I_{(9)}^2 + I_{(11)}^2}}{I_{(1)}}, \qquad (18)$$

where $I_{(3)}$, $I_{(5)}$, $I_{(7)}$, $I_{(9)}$, $I_{(11)}$ - effective values of the majority harmonics of a current, $I_{(1)}$ - effective value of the fundamental harmonic of a current.

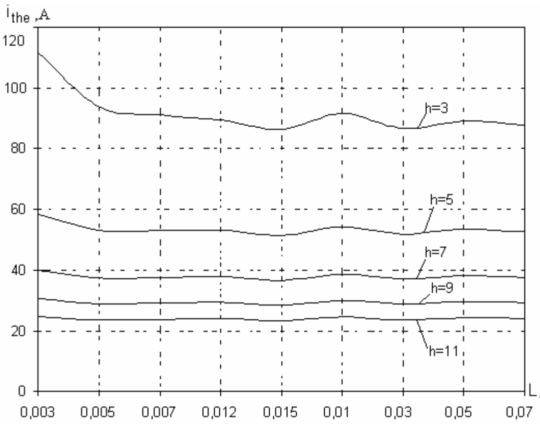

Fig. 6. Change of effective values of the majority harmonics of a current at C = 0.01 F and a loading current 300 A (results of computer modeling)

On Fig. 7. dependences *THD* on values *L* are represented at C = 0.01 F (that is, at very big capacitance). *THD* is calculated also at various currents of loading. As we see, on the average, it is possible to accept, that *THD* is at a level 0.4, what is not a bad parameter.

Conclusions

1. Expressions of acceptable accuracy for calculation of pulsations of an entrance current of the filter and pulsations of a voltage of the capacitor are received.
2. To receive 10 % a level of pulsations of an average current, it is necessary to use a reactor of the filter with the big inductance, which weight at a current about 300 A and can reach 1000 kg.
3. Researches of parameter *THD* show, that it is practically possible to allow much more the big pulsations of a current of the filter without essential increase of parameter *THD*. It means, that the reactor of the filter can be chosen by a principle of a continuity of an entrance current at the minimal current of loading.

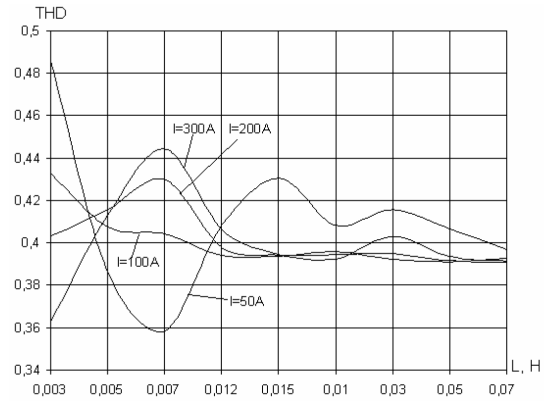

Fig. 7. A curve $THD = f(L)$ at C = 0.01 F (results of computer modeling)

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I. Rodionova, I. Raņķis. Įėjimo filtro darbo režimai // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2005. – Nr. 4(60). – P. 33–36.

Atliktas filtravimo LC filtru nevaldomame vienfaziame lygintuve tyrimas. Gautos išraiškos, aprašančios darbinius filtro režimus ir leidžiančios apskaičiuoti filtro elementų parametrus. Atliktas kompiuterinis modeliavimas, patvirtinantis gautų išraiškų teisingumą. Apskaičiuoti filtro droselio parametrai įvertinant priklausomybes nuo induktyvumo ir srovės, taip pat droselio masė. Įrodyta, kad THD veiksnys artimas 0,4 ir mažai priklauso nuo droselio srovės pulsacijų. Il. 7, bibl. 4 (anglų kalba; santraukos lietuvių, anglų ir rusų k.).

I. Rodionova, I. Raņķis. Operational Regimes of Input Filters // Electronics and Electrical Engineering. – Kaunas: Technologija, 2005. – No. 4(60). – P. 33–36.

In this paper an investigation of the L,C filter at output of the single-phase uncontrolled rectifier is done. Equations describing processes in such a filter and are providing possibility to calculate parameters of elements are obtained. Computer simulation realized for filter accepts a results of mathematical investigation. Calculated parameters of the equipment – the mass of reactor for different operational regimes and current of load are estimated. Is evaluated also an impact of the filter on harmonic distortion of the networks current. Is shown that THD indicator is very close to the figure 0.4 and in very small extent depends on level of reactor's current pulsation. Ill. 7, bibl. 4 (in English; summaries in Lithuanian, English, Russian).

И. Родионова, И. Ранькис. Рабочие режимы входного фильтра // Электроника и электротехника. – Каунас: Технология, № 4(60). – С. 33–36.

В работе рассмотрена фильтрация выпрямленного напряжения с L, C фильтром в неуправляемом однофазном выпрямителе. Получены выражения, которые описывают рабочие режимы фильтра, а также дают возможность рассчитать параметры элементов фильтра. Проведено компьютерное моделирование, которое подтверждает правильность полученных выражений. Рассчитаны параметры дросселя фильтра в зависимости от индуктивности и расчетного тока, а также масса дросселя фильтра. Исследовано влияние фильтра на гармонический состав переменного тока сети. Доказано, что фактор THD близок к 0,4 и мало зависит от пульсаций тока дросселя. Ил. 7, библ. 4 (на английском языке; рефераты на литовском, английском и русском яз.).