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АНАЛИЗ ПАРАМЕТРОВ И ХАРАКТЕРИСТИК ВЫХОДНЫХ ФИЛЬТРОВ du/dt ЭЛЕКТРОМАГНИТНОЙ СОВМЕСТИМОСТИ ТРЕХФАЗНЫХ ПРЕОБРАЗОВАТЕЛЕЙ ЧАСТОТЫ НА ЛИНЕЙНОЕ НАПРЯЖЕНИЕ 380 В

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В результате анализа параметров фильтров, выпускаемых фирмой Danfoss, получены аналитические выражения для определения их индуктивности и емкости в зависимости от мощности нагрузки преобразователя частоты. Определены численные значения важных для синтеза фильтров характеристик.

Ключевые слова: частотно-регулируемый электропривод, фильтр электромагнитной совместимости, преобразователь частоты, индуктивность, емкость.

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ANALYSIS OF PARAMETERS AND CHARACTERISTICS OF OUTPUT FILTERS du/dt ELECTROMAGNETIC COMPATIBILITY OF THREE PHASE FREQUENCY CONVERTERS ON 380 V PHASE-TO-PHASE VOLTAGE

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As a result of the analysis of the parameters of the filters produced by Danfoss, analytical expressions are obtained for determining their inductance and capacitance depending on the load power of the frequency converter. Numerical values of the characteristics important for the synthesis of filters are also determined.

Keywords: frequency-controlled electric drive, EMC filter, frequency converter, inductance, capacitance.

Introduction. The problems of electromagnetic compatibility are closely related to the reliability and safety of a frequency-controlled electric drive [1 - 5]. In particular, the requirements of [6] limiting the permissible amplitude of the pulse of the phase-to-phase voltage supplied from the frequency converter (FC) to the motor terminals, from the rise time of the pulse are established. Ordinary, a limitation is set on the rate of increase of the voltage coming from FC to motor, $du/dt = 500\ \text{V}/\ \mu\text{s}$. It also states that the voltage and voltage rise limits can be achieved by connecting inductor or a low-pass filter to the output of FC (a filter that effectively passes the frequency spectrum of the signal below the cutoff frequency and suppresses the frequency of the signal above this frequency), connected in series, and shunt capacitor.

One of the types of low-pass filters, practically used for the stated purpose, is a filter du/dt. The variant of its scheme is shown in Fig. 1. The filter consists of three phase reactors L and three capacitors C, each connected either between two phases (triangle circuit) or between phase and neutral point (wye circuit). Resistors R are added to adjust the high-frequency components of the voltage spectrum [1, 2]. However, resistors R that are parallel to L inductances may be absent. When using the filter du/dt, the voltage form on the motor terminals remains impulsive [1, 5].

It is known that for filters du/dt, the inductance values of the reactors and capacitors are selected in such a way that frequency suppression is provided above the switching frequency of the power keys of

the inverter (the cutoff frequency is much higher than the switching frequency of the transistors of the inverter (the carrier frequency of the pulse-width modulation)). The inductance is in the range from a few tens to several hundreds of μH, the capacitance of capacitors is within a few tens of nF. Filters du/dt can be used at lower switching frequencies of the transistor than the nominal frequency indicated for the filter. On the contrary, the switching frequencies above the rated frequency should be avoided, since work on them can lead to overheating of the filter [7]. However, this information is not enough to synthesize the filter.

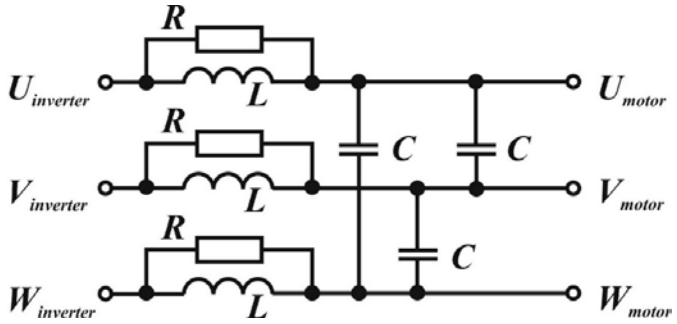

Fig. 1. A variant of the du/dt filter circuit

Formulation of the problem. The purpose of this article is to analyze known technical solutions in the field of du/dt filters and to derive on its basis the patterns for the synthesis of filter parameters for their design, modeling, and so on.

When developing a new device, it is always welcome to familiarize with existing analogues. As such an analogue, the basis for the analytical study, we will use the published data on Danfoss filters for a line voltage of 380 V [7]. Table. 1 contains the parameters and characteristics of the filters according to [7] (the active power of the three-phase load of the frequency converter P, the effective value of the load phase current I, the inductance of the filter phase L, the filter phase capacitance C, the maximum filter losses $\Delta p_{\max}$, the minimum switching frequency of the inverter f_s), and the results of calculations based on them (cutoff frequency f_c, voltage drop on the inductance at a frequency of 50 Hz as a percentage of the nominal phase voltage of 220 V $\Delta u_{L\%}$, frequency multiplicity f_c / f_s, the fraction of losses in the filter from the nominal load power $\Delta p_{\%}$, the equivalent active resistance of the filter phase R_{eqv}). We assume that the capacitance values in [7] are indicated for the case of their connection in the wye scheme.

Theory. Calculations in Table. 1 are satisfied by the following formulas:

$$f_c = \left(2\pi\sqrt{L \cdot C}\right)^{-1};$$

$$\Delta u_{L\%} = 2\pi \cdot f_1 \cdot L \cdot I \cdot 100\% / V,$$

where $f_1 = 50$ Hz; $V = 220$ V - effective value of phase voltage;

$$\Delta p_{\%} = \Delta p_{\max} \cdot 100\% / P;$$

$$R_{eqv} = \Delta p_{\max} / 3 / I^2.$$

Fig. 2 and Fig. 3 shows the equations of trend lines representing mathematical expressions relating the values of the du/dt filter parameters to the power of the three-phase load fed from the FC, and also the value of the accuracy of the approximation by the trend line given in Table. 1 parameter values (point-

markers) is the coefficient of determination, informing about the extent to which this trend explains the location of the initial points.

Table 1

Parameters and characteristics of filters

Initial data [3]						Calculation results				
P	I	L	C	Δp_{max}	f_s	f_c	f_c / f_s	$\Delta u_{L\%}$	$\Delta p_{\%}$	R_{eqv}
kW	A	μH	nF	W	kHz	kHz	p. u.	%	%	mOhm
11	24	150	10		4	130	32	0,51		
15	32	150	10		4	130	32	0,69		
18,5	37,5	150	10		4	130	32	0,80		
22	44	150	10	37	4	130	32	0,94	0,17	6,37
30	61	110	13,6		3	130	43	0,96		
37	73	110	13,6		3	130	43	1,15		
45	90	110	13,6	130	3	130	43	1,41	0,29	5,35
55	106	95	15	145	3	133	44	1,44	0,26	4,30
75	147	111	15		3	123	41	2,33		
90	177	111	15	205	3	123	41	2,81	0,23	2,18
110	212	50	20		3	159	53	1,51		
132	260	50	20		3	159	53	1,86		
160	315	50	20	315	3	159	53	2,25	0,20	1,06
200	395	30	43		3	140	47	1,69		
250	480	30	43	398	3	140	47	2,06	0,16	0,58
315	600	17	66		2	150	75	1,46		
355	658	17	66	550	2	150	75	1,60	0,15	0,42
400	745	13	99		2	140	70	1,38		
450	800	13	99		2	140	70	1,49		
500	880	13	99	850	2	140	70	1,63	0,17	0,37

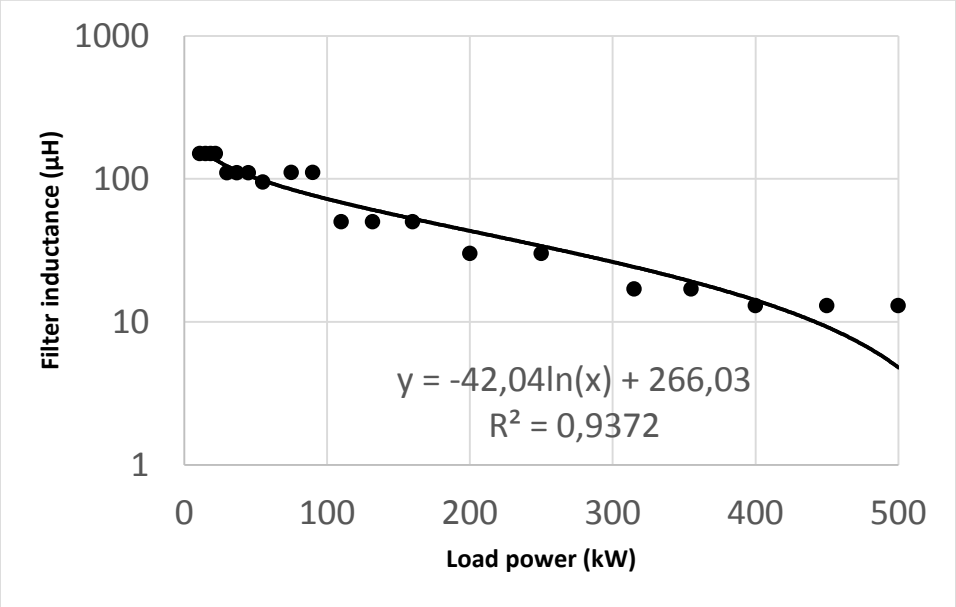

Fig. 2. Approximation of the du/dt filter inductance per phase by analytic function

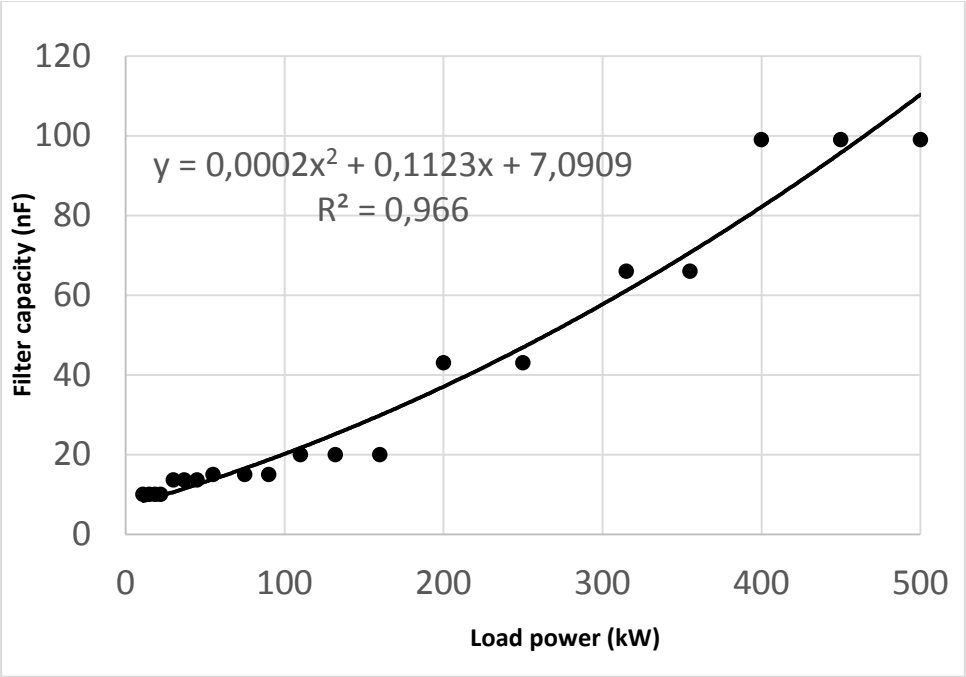

Fig. 3. Approximation of the du/dt filter capacitance per phase by analytic function

Conclusion. As a result of analyzing the parameters of the filters produced by Danfoss, analytical expressions for determining L and C depending on the power of the FC load are obtained, and the values of the characteristics that are important for the synthesis of filters are calculated: $f_{\text{р}} / f_{\text{к}}$, $\Delta u_{L\%}$ и $\Delta p_{\%}$.

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