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# FEATURES OF DETERMINING CRITERIA OF SIMILARITY FOR FREQUENCY OF ELECTRIC DRIVES

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**Abstract.** The article describes the application of the similarity theory for a frequency-driven electric drive that allows the results of an exploratory model to be transferred to an object of similarity. At large industrial enterprises a large number of such electric drives of various designations are used, the experimental study of which is impossible to assess the impact on the technological process or the research is difficult due to the fulfilment of the technological task. For this it is necessary, on the basis of the  $\pi$ -theorem, to compile similarity criteria for power drives of different frequency, which are used in research and applied in an industrial enterprise.

Frequency drive is a set of electromechanical devices, including a frequency converter and an asynchronous motor [1]. The use of such devices provides a reduction in power consumption, depending on the operating mode up to 25%. Along with the optimization and improvement of the quality of the process, such electrical appliances are the cause of higher harmonics of current and voltage of the generators being fed into the power system [2]. To determine the degree of influence of non-sinusoidal mode on the power supply system for such electric receivers, it is necessary to conduct experimental studies on electromagnetic compatibility [3].

The complexity of such an experiment lies in the impossibility of investigating each frequency drive and the permissible change in its operating mode. In order to carry out the studies with different operating modes of the applied electric drives, it is necessary to develop criteria for the similarity of complex systems for an electric drive of lower power that is in accordance with an industrial electric drive. To this end, it is necessary to develop the criteria for the similarity of a frequency electric drive for the possibility of transferring the received characteristics from a research object to an industrial object.

The aim of the work is to develop similarity criteria and scale factors of different in frequency power electro-drives.

The similarity theory and the criteria developed with its help make it possible to establish the presence of similarity of complex systems or to develop methods for obtaining it in the form of scale ratios, complex functional dependencies of groups of parameters of the objects being compared. Similarity criteria are the establishment of the correspondence between the compared objects and the processes occurring in them, in which the functions of the objects are known, and the mathematical descriptions allow their transformation to the identical form [4].

For the construction of  $\pi$ -criteria, according to the first supplementary provision on the similarity of complex systems, to determine the likelihood of a frequency drive, we apply the method of structural modeling, on the basis of which it is possible to single out individual subsystems: an autonomous voltage inverter (AIN), an uncontrolled rectifier (HB), LC-filter (PZPT) and the asynchronous motor (AD). Let us write down the generalized system of scalar equations of each element of a two-link frequency converter in a system of moving coordinates  $[u; v]$ , which are fundamental for the original object. Such a system of coordinate axes at  $\omega_k = 0$  is used to describe processes in electric drives in which the output voltage of a semiconductor frequency converter is not sinusoidal, also the current in phase coincides with the  $u$  axis, and always corresponds to the real phase current [5].

The system of equations (3-6), where each element of the subsystem of a record with a prime, will refer to the similarity model. On the basis of an additional provision on the similarity of complex systems consisting of sub-systems and using the Fourier rule, we define  $\pi$ -criteria, using the reduction of equa-



tions to the dimensionless form with the help of integral analogues [6]. In this case, the compared processes in the original object and the similarity object are similar, therefore, between their similar parameters there must exist proportionality relations, an example for the third equation (5):

$$\begin{aligned} i_c &= m_{i_c} \cdot i_c'; \\ i_\theta &= m_{i_\theta} \cdot i_\theta'; \\ i_u &= m_{i_u} \cdot i_u', \end{aligned} \quad (1, 2)$$

where  $m_i$  – scale factors.

### 1.1. Equations of the AIN

$$\begin{aligned} f_u &= \frac{u_u^*}{2 \cdot U_0}, f_v = \frac{u_v^*}{2 \cdot U_0}, \\ u_{uu} &= u_u \cdot f_u, u_{uv} = u_u \cdot f_v, i_u = \frac{3}{2}(i_{1u} \cdot f_u + i_{1v} \cdot f_v); \end{aligned} \quad (3)$$

### 1.2. Equations of the HB

$$\begin{aligned} u_u &= u_{\theta u}, u_v = u_{\theta v}, f_{\theta u} = \frac{2 \cdot \sqrt{3}}{\pi} \cos \theta_i, f_{\theta v} = \frac{2 \cdot \sqrt{3}}{\pi} \sin \theta_i, \\ u_\theta &= \frac{3}{2}(u_{\theta u} \cdot f_{\theta u} + u_{\theta v} \cdot f_{\theta v}), i_u = i_\theta \cdot f_{\theta u}, i_v = i_\theta \cdot f_{\theta v}; \end{aligned} \quad (4)$$

### 1.3. Equations of the PZPT

$$\frac{di_\theta}{dt} = \frac{u_\theta - u_u}{L_{p\phi}}, \frac{du_u}{dt} = \frac{i_c}{C_{\phi\phi}}, i_c = i_\theta - i_u; \quad (5)$$

### 1.4. Equations of the AD

$$\begin{aligned} u_{1u} &= \frac{d\psi_{1u}}{dt} - \omega_k \psi_{1v} + R_1 i_{1u}, u_{1v} = \frac{d\psi_{1v}}{dt} - \omega_k \psi_{1u} + R_1 i_{1v}, J \frac{d\omega_\varphi}{dt} = M - M_c, \\ 0 &= \frac{d\psi_{2u}}{dt} - \omega_k \psi_{2v} - \omega_\varphi \psi_{2v} + R_2 i_{2u}, 0 = \frac{d\psi_{2v}}{dt} + \omega_k \psi_{2u} - \omega_\varphi \psi_{2u} + R_2 i_{2v}, \\ M &= \frac{3}{2} p_n \Psi_{0u} i_{1v} - \frac{3}{2} p_n \Psi_{0v} i_{1u}; \end{aligned} \quad (6)$$

where  $u_u^*, u_v^*$ -giving effects;  $f_u, f_v$ - modulation index;  $U_0$  is the amplitude of the reference voltage;  $u_u$  - the voltage of the power supply of the inverter;  $i_u$  - the average current of the inverter;  $u_{uu}, u_{uv}$  - the average output voltage of the inverter;  $i_{1u}, i_{1v}$  - average inverter output currents;  $u_u, u_v, i_u, i_v$  are the transformed voltage harmonics at the power input of the NV and the network currents;  $f_{\theta u}, f_{\theta v}$  - transformed harmonics of switching functions HB;  $\theta_i$  is the angle of rotation of the resulting network current vector, with respect to the phase axis A of the mains voltage;  $u_\theta, i_\theta$  - voltage and current at the output HB;  $L_{p\phi}$  is the inductance of the smoothing reactor LC filter;  $C_{\phi\phi}$  - capacitance battery capacitance capacitor;  $i_c$  - current of the capacitor;  $u_{1u}, u_{1v}, i_{1u}, i_{1v}, \psi_{1u}, \psi_{1v}$  are respectively the transformed voltages and the total fluxes of the stator windings;  $i_{2u}, i_{2v}, \psi_{2u}, \psi_{2v}$  are the transformed currents and the total flux linkages of the rotor winding;  $\psi_{0u}, \psi_{0v}$  - main flux linkage;  $p_n$  is the number of pairs of poles.

The criteria for the similarity of a frequency electric drive (according to the rule of integral analogs) are obtained by reducing the equations to the dimensionless form:

#### 1.4.1. for the system of equations AIN:

$$\begin{aligned} \pi_1 &= \frac{0.5 \cdot u_u^*}{U_0 \cdot f_u}; \quad \pi_2 = \frac{0.5 \cdot u_v^*}{U_0 \cdot f_v}; \\ \pi_4 &= \frac{u_u \cdot f_v}{u_{uv}}; \quad \pi_5 = \frac{1.5 \cdot i_{1u} \cdot f_u}{i_u}; \quad \pi_6 = \frac{1.5 \cdot i_{1v} \cdot f_v}{i_u}; \end{aligned} \quad (7-11)$$

1.4.2. for the system of equations HB:

$$\begin{aligned}\pi_7 &= \frac{u_{Bu}}{u_u}; \quad \pi_8 = \frac{u_{Bv}}{u_v}; \\ \pi_9 &= \frac{1.103 \cdot \cos \theta}{f_{Bu}}; \quad \pi_{10} = \frac{1.103 \cdot \sin \theta}{f_{Bv}}; \quad \pi_{11} = \frac{1.5 \cdot u_{Bu} \cdot f_{Bu}}{u_B}; \\ \pi_{12} &= \frac{1.5 \cdot u_{Bv} \cdot f_{Bv}}{u_B}; \quad \pi_{13} = \frac{i_B \cdot f_{Bu}}{i_u}; \quad \pi_{14} = \frac{i_B \cdot f_{Bv}}{i_v};\end{aligned}\quad (12-19)$$

1.4.3. for the system of equations PZPT:

$$\begin{aligned}\pi_{15} &= \frac{u_B \cdot t}{L_{p\phi} \cdot i_B}; \quad \pi_{16} = \frac{u_u \cdot t}{L_{p\phi} \cdot i_B}; \\ \pi_{17} &= \frac{i_c \cdot t}{C_{6\phi} \cdot u_u}; \quad \pi_{19} = \frac{i_u}{i_c}; \quad \pi_{18} = \frac{i_B}{i_c};\end{aligned}\quad (20-24)$$

1.4.4. for the system of equations AD:

$$\begin{aligned}\pi_{20} &= \frac{\Psi_{1u}}{R_1 i_{1u} t}; \quad \pi_{21} = \frac{u_{1u}}{R_1 i_{1u}}; \\ \pi_{22} &= \frac{\Psi_{1v}}{R_1 i_{1v} t}; \quad \pi_{23} = \frac{u_{1v}}{R_1 i_{1v}}; \quad \pi_{24} = \frac{\Psi_{2u}}{R_2 i_{2u} t}; \quad \pi_{25} = \frac{\omega_3 \Psi_{2v}}{R_2 i_{2u}}; \\ \pi_{26} &= \frac{\Psi_{2v}}{R_2 i_{2v} t}; \quad \pi_{27} = \frac{\omega_3 \Psi_{2u}}{R_2 i_{2v}}; \quad \pi_{28} = \frac{P_n \Psi_{0u} i_{1v}}{M}; \quad \pi_{29} = \frac{P_n \Psi_{0v} i_{1u}}{M}; \\ \pi_{30} &= \frac{J \omega_3}{M t}; \quad \pi_{31} = \frac{M_c}{M}.\end{aligned}\quad (25-36)$$

Similarity of processes in the original and similarity means that they, having qualitatively the same character and differing only in scale, should be described by the same mathematical equations. Obviously, the similarity object will also describe the processes in the frequency drive - in the event that the ratios of the scaling coefficients for the associated terms of the homogeneous equation are equal, an example for (20-24):

$$\begin{aligned}I_{\pi 1} &= \frac{u_b \cdot t \cdot L'_{pf} \cdot i'_b}{u'_b \cdot t' \cdot L_{pf} \cdot i_b} = 1; \quad I_{\pi 2} = \frac{u \cdot t \cdot L'_{pf} \cdot i'_b}{u'_u \cdot t' \cdot L_{pf} \cdot i_b} = 1; \\ I_{\pi 3} &= \frac{i_c \cdot t \cdot C'_{bf} \cdot u'_u}{i'_c \cdot t' \cdot C_{bf} \cdot u_u} = 1; \quad I_{\pi 4} = \frac{i_b \cdot i'_c}{i'_b \cdot i_c} = 1; \quad I_{\pi 5} = \frac{i_u \cdot i'_c}{i'_u \cdot i_c} = 1.\end{aligned}\quad (37-41)$$

where parameters written with a stroke refer to a similarity model.

A feature of the similarity of such complex systems as a frequency electric drive consisting of subsystems HB, PZPT, AIN and AD, respectively, similar for the research electric drive and the industrial object, it is necessary that the similarity criteria for these subsystems be equal (7-41), which are composed of the parameters (3-6) common to these subsystems.

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