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The principles of the creation of the control system for the pumping complex variable-frequency electric drive, taking into account the alteration of the current parameters of the hydrosystem

***Abstract**. We demonstrated that the alteration of the basic parameters of the pumping and pipeline equipment accompany the pumping complexes functioning in the unsteady operation modes. We considered the special features of the creation of the extreme system of the automatic control of the pumping complex variable-frequency electric drive taking into account the alteration of the current parameters of the electrohydraulic equipment. We presented the algorithm of the operation of the considered extreme system. The algorithm grounds on the identification of the pumping complex parameters based on the equations of the balance of the hydraulic power harmonic components between the power supply and the elements of the hydrosystem.*

Streszczenie.** Wykazano, że zmienność podstawowych parametrów pompowania i wyposażenia rurociągowego wprowadza system pompowania w stan nieustalony. Rozważono specjalne właściwości tworzenia ekstremalnego systemu automatycznego sterowania napędem zespołu pompowego przy zmienności parametru prądowego w urządzeniu elektrohydraulicznym. Zaprezentowany został algorytm działania rozważanego systemu ekstremalnego. Algorytm bazuje na identyfikacji parametrów zespołu pompowego bazujące na równaniu równowagi pomiędzy mocą zasilania i elementów hydrosystemu. **(Zasady tworzenia systemu sterowania systemu pompowania za pomocą zmienno-częstotliwościowego napedu elektrycznegozęstotliwości, biorąc pod uwagę zmienność parametrów prądowych hydrosystemu)

Keywords: pumping complex, parameter identification, extreme system, fuzzy-regulator.
Słowa kluczowe:system pompowania, identyfikacja parametru, system ekstremalny, regulator rozproszony

Introduction

In the practice of pumping complexes (PC) operation, there often occur unsteady processes caused by the development of complex hydrodynamic phenomena: surges, cavitation oscillations, turbulent modes, water hammers, etc. [1, 2]. The unstable flow of liquid in the hydrosystem characterized by the alteration of the head and discharge signals in time accompanies them.

PC operation in the unsteady modes results in the deviation of the parameters (resistive impedance, inductance and capacitance) of the pump unit (PU) and the hydronetwork from their rated values and, consequently, in the inefficient operation of the electrotechnical equipment. The shift of the point of PC operation mode causes it and results in the reduction of PU efficiency.

Taking into consideration the above said, when developing automatic control systems (ACS) with a variable-frequency electric drive (VFED) of PC, solving the basic technological problem (the stabilization of the head or discharge in the hydronetwork). It is necessary to take into account the alteration of the current parameters of the pumping and pipeline equipment resulting in the deviation of PC operation mode from the domain with the maximal possible efficiency.

Research method

Fig. 1 contains a block diagram of the extreme ACS of PC VFED, with the maintenance of the required pressure at the consumer, including: a pump (P) with a drive induction motor (IM), a frequency converter (FC) connected to IM stator windings, a pipeline network, a consumer (C), a controlled stopcock (S) with an actuating mechanism (AM), pressure sensors (PS1–PS3) and discharge sensors (DS1–DS3), a velocity sensor (VS), a calculation block (CB) containing an input data block (IDB), a setting signal formation block (SSFB), a power determination block, a frequency analysis block (FAB), a block for the determination of the pump efficiency (BDE), a parameter identification block (PIB), comparison devices (CD1, CD2), a fuzzy-regulator (FR) and a PID-regulator.

The proposed extreme ACS is to provide the search of the PC operation mode with maximal possible efficiency at the stabilization of the pressure in the pipeline network taking into account the alteration of the current parameters of the hydrosystem. The above said is performed via the joint use of the PID-regulator and the fuzzy-regulator within the ACS structure. The basic task of the PID-regulator consists in the formation of the control signal $u_{con1}(t)$ to the frequency converter for the step-by-step alteration of the rotation frequency of the pump induction motor aiming at the maintenance of the pressure at the consumer. In this case the fuzzy-regulator produces signal $u_{cor}(t)$ for the correction of the setting signal $u_{zad\,cor}(t)$, coming to the input of the PID-regulator aiming at the provision of the maximal efficiency of PU at the corresponding deviations of the current parameters ($\Delta R_p, \Delta R_{net\,i}, \Delta L_{net\,i}, \Delta C_{net\,i}, \Delta R_{con}$) of the hydrosystem. It should be noted that the pump efficiency is a nonlinear function $\eta = f(\omega, \alpha)$, depending on the rotation frequency ω of the drive motor and the rotation angle α of the controlled stopcock S.

The current parameters of the hydrosystem are identified based on the frequency analysis of the hydraulic power [3] obtained at PC elements by the performance of the corresponding signals of the head $H(t)$ and discharge $Q(t)$.

Below there are expressions for the determination of the power [4, 5]:

of the hydraulic power supply

$$p_s(t) = \rho g H_0 \nu^2(t) Q_p(t) \quad (1)$$

at PU output

$$p_p(t) = \rho g H_p(t) Q_p(t) \quad (2)$$

at the *i*- th section of the pipeline

$$p_{net\,i}(t) = \rho g H_{net\,i}(t) Q_{net\,i}(t) \quad (3)$$

at the consumer

$$p_{con}(t) = \rho g H_{con}(t) Q_{con}(t) \quad (4)$$

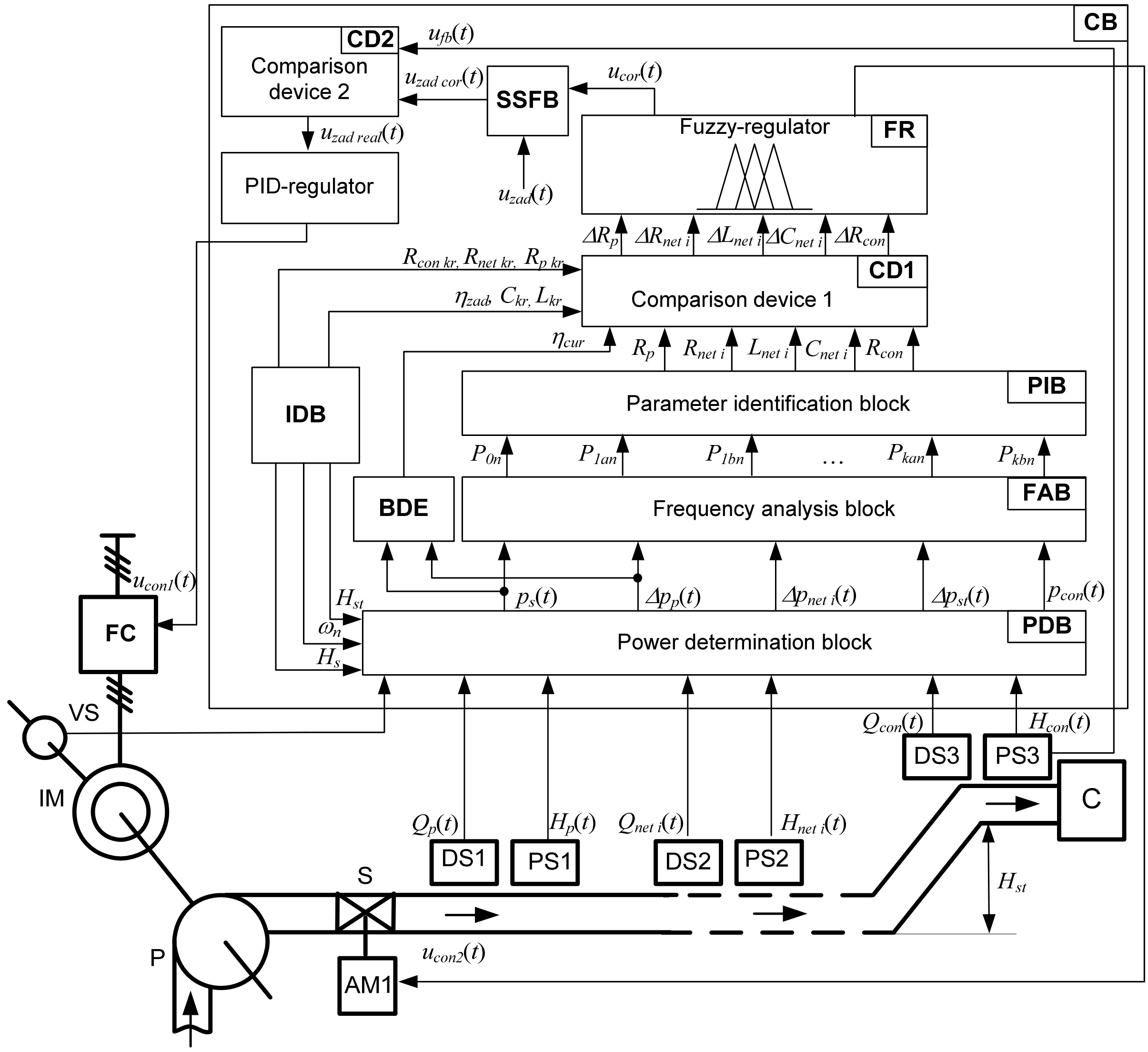

Fig. 1. A block diagram of ACS of PC VFED

the hydraulic power losses:

at the pump output

(5) $$\Delta p_p(t) = p_s(t) - p_p(t)$$

at the *i*- th section of the pipeline

(6) $$\Delta p_{net\,i}(t) = p_{net\,i}(t) - p_{net\,i+1}(t)$$

for overcoming the counter-pressure in the pipeline network

(7) $$\Delta p_{st}(t) = H_{st} Q_{con}(t).$$

In expressions (1)–(7) the following designations are adopted: H_0 – PU head at zero discharge; $\nu(t) = \omega_i(t)/\omega_n$ – the relative rotation frequency of the pump unit; ω_i, ω_n – the current and the rated values of the motor rotation frequency, respectively, s^{-1}; H_{st} – the source of the static counter-pressure, m; $H_p(t), H_{net\,i}(t), H_{con}(t)$, $Q_p(t), Q_{net\,i}(t), Q_{con}(t)$ – the signals of the head and discharge at PU output, at the *i*-th section of the pipeline and at the consumer, respectively; $g = 9.81$ m/s^2 – the acceleration of gravity; ρ – the density of the liquid.

At the development of unsteady processes in the pipeline, the discharge signal is of a periodic non-sinusoidal nature. That is why it can be presented by a trigonometric series of the form:

(8) $$Q_n(t) = Q_{0n} + \sum_{j=1}^{J} Q_{an\,j} \cos(\Omega_j t) + \sum_{j=1}^{J} Q_{bn\,j} \sin(\Omega_j t)$$

where j, J – the number and the quantity of the discharge signal harmonics, respectively; $Q_{an\,j}$, $Q_{bn\,j}$ – the orthogonal cosine and sine components of the discharge signal, respectively; Ω_j – the circular frequency of the discharge signal.

The use of the frequency analysis method allows the representation of the hydraulic power at the n -th element of PC by a sum of the constant and variable (cosine and sine) components [4]. Such an approach makes it possible to obtain the frequency characteristics of the power signals (the amplitude and the phase spectra) at the periodic alteration of the technological parameters in PC hydronetwork, to determine the indices of energy conversion between the power supply and the consumer [3, 5].

Therefore, e.g. the power at the output of the hydraulic power supply is:

$$p_s(t)=\rho g H_0 \nu^2 Q_p(t)=\rho g H_0 \nu^2 \times$$

$$(9)\quad \times\left(\sum_{l=1}^{L} Q_{l0\,i}+\sum_{l=1}^{L} Q_{la\,i}\,cos(\Omega_{kav}t)+\sum_{l=1}^{L} Q_{lb\,i}\,sin(\Omega_{kav}t)\right)=$$

$$=\sum_{r=1}^{R} P_{sr0}+\sum_{r=1}^{R} P_{sra}\;cos(\Omega_s t)+\sum_{r=1}^{R} P_{srb}\;sin(\Omega_s t)$$

where $\sum_{r=1}^{R} P_{sr0}=H_0\sum_{l=1}^{L} Q_{l0\,i}$ – the constant component of the power at the output of the hydraulic power supply; $\sum_{r=1}^{R} P_{sra}=H_0\sum_{l=1}^{L} Q_{la\,i}$, $\sum_{r=1}^{R} P_{srb}=H_0\sum_{l=1}^{L} Q_{lb\,i}$ – the cosine and sine components of the first harmonic of the power of the hydraulic power supply, respectively; $\Omega_s=\Omega_{kav}$ – the circular frequency of the power of the hydraulic power supply.

Substituting (8) into expressions (2)–(7) and performing the necessary transformations, we obtain the dependences of the hydraulic power for all PC elements in the form of harmonic components.

Taking into account the distribution of the power losses at the elements of PC power channel, the equation of the energy balance of the hydraulic power harmonic components between the power supply (the pump unit) and the elements of the pipeline network is of the form [6]:

$$(10)\qquad p_s(t)=\Delta p_p(t)+\Delta p_{net\,i}(t)+\Delta p_{st}(t)+p_{con}(t).$$

The harmonic analysis of the power components included in (10), allowed obtaining the identification equations in the form of the equations of energy balance for separate components of the hydraulic power between the hydraulic power supply and PC elements:

$$(11)\quad \left.\begin{array}{l} P_{s0}=\Delta P_{st0}+\Delta P_{p0}+\Delta P_{net\,i0}+P_{con0};\\ P_{s1a}=\Delta P_{st1a}+\Delta P_{p1a}+\Delta P_{net\,i1a}+P_{con1a};\\ P_{s1b}=\Delta P_{st1b}+\Delta P_{p1b}+\Delta P_{net\,i1b}+P_{con1b};\\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\\ P_{ska}=\Delta P_{stka}+\Delta P_{pka}+\Delta P_{net\,ika}+P_{conka};\\ P_{skb}=\Delta P_{stkb}+\Delta P_{pkb}+\Delta P_{net\,ikb}+P_{conkb} \end{array}\right\}$$

where the power constant components correspond to index "0"; the cosine and sine components correspond to indices "a", "b", respectively; ΔP_p – the amplitude value of the hydraulic power losses at PU output; ΔP_{st} – the amplitude value of the losses of the hydraulic power spent on overcoming the static counter-pressure; $\Delta P_{net\,i}$ – the amplitude value of the hydraulic power losses at the i - th section of the hydronetwork; P_{con} – the amplitude value of the hydraulic power at the consumer; *k* – the number of the harmonic.

The solution of the obtained system of nonlinear equations by the Jacobi iteration method enabled the determination of the current parameters of PC elements: resistive impedance $R_p, R_{net\,i}, R_{con}$, inductance $L_{net\,i}$ and capacitance $C_{net\,i}$ of the hydronetwork. The advantages of this method consist in the possibility of the setting of a wide spectrum of the initial approximations of the sought functions and obtaining the results with the assigned accuracy.

The succession of the performance of the procedure of PC parameters identification is given in Fig. 2.

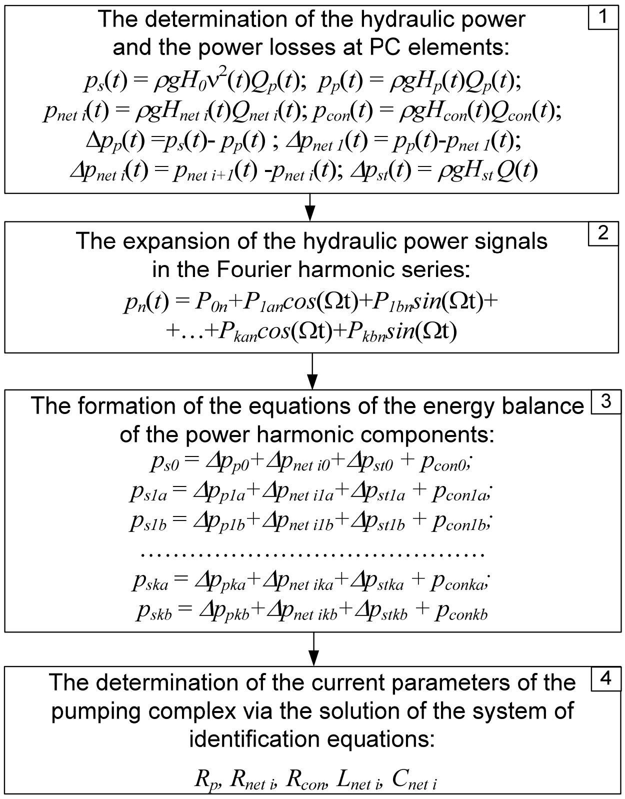

Fig. 2. The stages of the identification of PC parameters

Taking into account the above said, Fig. 3 shows a generalized algorithm of the operation of ACS of PC VFED including the following basic stages:

the introduction of the hydrosystem input data: $H_{st}, \omega_n, H_s, R_{p\,kr}, R_{net\,i\,kr}, L_{net\,i\,kr}, C_{net\,i\,kr}, R_{con\,kr}, \eta_{zad}$;

the readout of the control-measuring equipment;

the start of the procedure of PC parameter identification [4, 6];

the comparison of the obtained results with the critical ($R_{p\,kr}, R_{net\,i\,kr}, L_{net\,i\,kr}, C_{net\,i\,kr}$) values;

the formation of the correcting setting signal to the input of the PID-regulator.

Conclusions

We have formulated the principles of the creation of the extreme control system for the pumping complex electric drive taking into account the alteration of the current parameters of the hydrosystem providing the stabilization of the head in the hydronetwork with the maximal possible efficiency of the pump unit. In this case, to perform the above said, the structure of the control system includes a fuzzy-regulator providing the correction of the setting signal to the PID-regulator. We have demonstrated that the current parameters of the pumping complex are determined via the identification of the resistive impedances and reactances of the hydrosystem based on the equations of the energy balance of the hydraulic power harmonic components between the power supply and the elements of the technological complex. We have proposed the algorithm of the operation of the extreme system of the pumping complex variable-frequency electric drive, including the procedure of the identification of the parameters of the electric equipment.

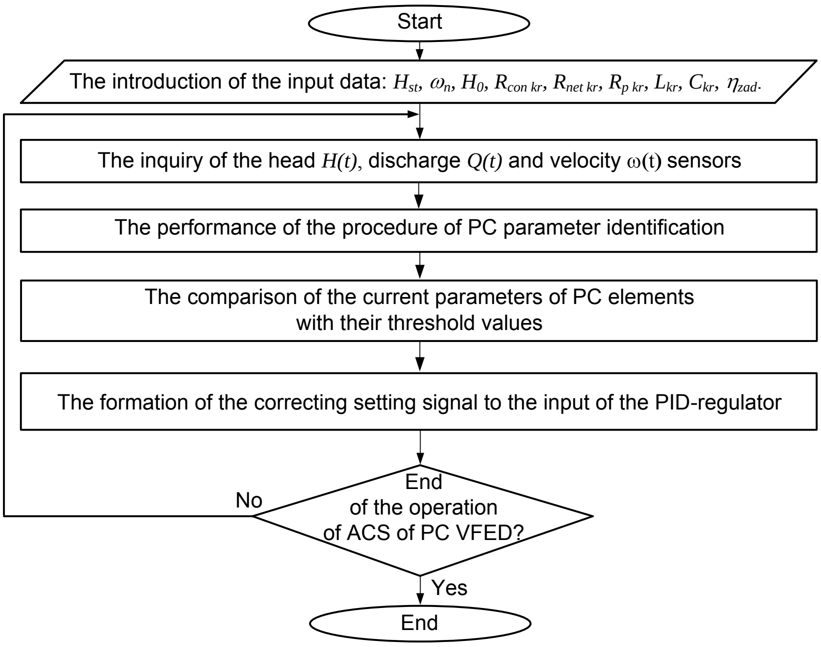

Fig. 3. The generalized algorithm of the operation of the extreme ACS of PC VFED

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REFERENCES

[1] Pejović S, Boldy A.P., Obradović D. Guidelines to hydraulic transient analysis, Technical Press, 1987, 145 p.

[2] Nicolet, C.; Kaelbel, T.; Alligne, S.; Ruchonnet, N.; Allenbach, P.; Bergant, A. and Avellan, F. (2011), Simulation of water hammer induced column separation through electrical analogy, 4-th International Meeting on Cavitation and Dynamic Problems in Hydraulic Machinery and Systems, October, 26-28, 2011, Belgrade, Serbia.

[3] M. Zagirnyak, V. Kovalchuk, and T. Korenkova, "Estimation of electromechanical systems power controllability according to instantaneous power component", Proceedings of International IEEE Conference IEPS 2014, Kyiv, Ukraine, pp. 266–272, IEEE Catalog Number CFP1405X-PRT, ISBN 978-1-4799-2266-6, 2014.

[4] Zagirnyak M., Kovalchuk V., Korenkova T. Power Model of an Electrohydraulic Complex with Periodic Nonlinear Processes in the Pipeline Network, 2015 International Conference on Electrical Drives and Power Electronics (EDPE), Tatranská Lomnica, The High Tatras, Slovakia September 21–23, 2015, pp. 345–352. IEEE Catalog Number CFP15EDQ-USB, ISBN 978-1-4673-9661-5

[5] Zagirnyak M., Kovalchuk V., Korenkova T. Harmonic analysis of power in an electrohydraulic complex with nonlinear processes in the pipeline system, Proceedings of 2016 IEEE International Conference on Intelligent energy and power systems (IEPS), Kyiv, Ukraine, 2016, pp. 143–148. IEEE Catalog Number: CFP1405X–PRT ISBN: 978-1-4799-2265-9

[6] M. Zagirnyak, V. Kovalchuk, and T. Korenkova, "Identification of electrohydraulic complex parameters using instantaneous power component", Przeglad Elektrotechniczny (Electrical review), no. 12b, pp. 286–289, 2013.