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INNOVATIVE DIRECTIONS OF IMPROVING ELECTRIC DRIVE OF SUCKER ROD PUMPING UNITS

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ИННОВАЦИОННЫЕ НАПРАВЛЕНИЯ СОВЕРШЕНСТВОВАНИЯ ЭЛЕКТРОПРИВОДА СКВАЖИННЫХ ШТАНГОВЫХ НАСОСНЫХ УСТАНОВОК

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Liquid lifting from low-rate oil wells is carried out with sucker rod pumping units (SRPU) with plunger`s electric drive from asynchronous electromechanical energy converters. Depending on the rotational speed of rotor shaft asynchronous power converters lift liquid from low-rate oil wells continuously or cyclically. There are some drawbacks of the cyclical operation mode of low-rate oil wells. When using pumping unit`s regular mechanical equipment to switch to a continuous mode liquid lifting from low-rate wells it is required to use asynchronous electromechanical energy converters with a low rotational speed. The article gives information about development of asynchronous energy converters with magnetic field rotation frequency 200 min-1, capacity 3 kW. It offers an innovative way to improve the energy efficiency of low-speed asynchronous energy converters, which is based on the idea of reactive magnetizing current`s internal compensation. The practical implementation of this idea provides a location in the stator slots the electromechanical energy converter of additional compensation winding and its connection to capacitors. The article describes a technique of selecting parameters of the compensation winding and capacitors, providing increase in power factor of electromechanical converter to a value of 1.0. The substantiation of the provisions that additional compensation winding`s location in stator slots of the asynchronous electromechanical power converter does not affect the value of efficiency coefficient. Serial production and widespread introduction in SRPU low-speed asynchronous energy converters, which carry reactive magnetizing current compensation, will significantly increase the volume of produced fluid from oil wells with low flow rate and raise energy efficiency of oil production.

Ключевые слова:
низкодебитная нефтяная скважина, непрерывный режим эксплуатации, инновационный тихоходный электромеханический преобразователь энергии, энергетические показатели, энергетическая эффективность.

Подъем жидкости из низкодебитных нефтяных скважин осуществляется скважинными штанговыми насосными установками (СШНУ) с электроприводом плунжера от асинхронных электромеханических преобразователей энергии. В зависимости от частоты, с которой вращается вал ротора асинхронного преобразователя энергии, подъем жидкости из низкодебитных нефтяных скважин осуществляется циклически или непрерывно. Отмечаются недостатки, присущие циклическому режиму работы низкодебитных нефтяных скважин. При использовании штатного механического оборудования станка-качалки для перехода к непрерывному режиму подъема жидкости из низкодебитных скважин требуются асинхронные электромеханические преобразователи энергии с низкой частотой вращения. Приводится информация о разработке асинхронных преобразователей энергии с частотой вращения магнитного поля 200 мин$^{-1}$ мощностью 3 кВт. Предлагается инновационное направление повышения энергетической эффективности тихоходных асинхронных преобразователей энергии, в основу которого положена идея внутренней компенсации реактивного намагничивающего тока. Практическая реализация данной идеи предусматривает размещение в пазах статора электромеханического преобразователя энергии дополнительной компенсационной обмотки и подключение ее к конденсаторам. Излагается методика выбора параметров компенсационной обмотки и конденсаторов, обеспечивающих повышение коэффициента мощности электромеханического преобразователя до значения, равного 1,0. Дается обоснование положения о том, что размещение в пазах статора асинхронного электромеханического преобразователя энергии дополнительной компенсационной обмотки не сказывается на значении коэффициента полезного действия. Серийный выпуск и широкое внедрение в приводе СШНУ тихоходных асинхронных преобразователей энергии, которые осуществляют компенсацию реактивного намагничивающего тока, позволят существенно увеличить объемы добываемой жидкости из нефтяных скважин с низким дебитом и поднять энергетическую эффективность производства нефтяной продукции.

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Introduction

Liquid lifting from low-rate oil wells is carried out with sucker rod pumping units (SRPU). The reciprocating movement of the movable part of the pump (plunger) is provided by electrical and mechanical equipment, pumping units. The composition of the electric equipment includes electromechanical energy converter, an asynchronous motor rotor winding made like "squirrel cage" is used typically [1]. Pumping unit mechanical equipment includes V-belt transmission, gearbox, crank mechanism, balancer, rope suspension, polished rod and sucker rod system.

The number of the plunger double strokes o up and down in a minute, which equals the number of balance swings per minute is determined by the formula

$$n_{\text{b}} = n\frac{1}{k_1 k_2}, \qquad (1)$$

where n − rotation frequency of the rotor shaft electromechanical converter; k_1 − V-belt transmission gear ratio; k_2 − reductor gear ratio; $n = n_0(1-s)$, $n_0 = 60f/p$, f – the frequency stresses of power line; p − the number of the stator winding pairs poles; s − rotor shaft slipping relative to the stator field, $s = (n_0 - n)/n_0$.

For such SKD-type pumping units the number of balancer swing per minute is in the range 4.2-14.7 min^{-1} [2]. The lower value of swing balancer is provided by installing on pumping units asynchronous electromechanical energy converters with the 750 min^{-1} stator magnetic field rotation frequency and locating of the smallest diameter pulley on the rotor shaft, where the value of k_1 is the maximum. The upper value of swing balancer is achieved by installing on pumping units of asynchronous electromechanical energy converters the 1500 min^{-1} stator magnetic field rotation frequency and locating the maximum diameter pulley on rotor shaft, wherein k_1 is the minimum.

Cyclic mode of the liquid selection from low rate wells and drawbacks of this mode

The liquid production from the low rate oil wells can be carried out continuously or cyclically. The using mode of operation low rate wells is largely determined by the number of swing balancer. Investigations have shown [3-5] if the number of a swing balancer is more then 4, as a rule, the cyclic mode of low-rate wells operation is provided. The liquid pumping periods alternate with SSHNU stop period, during which an fluid accumulation in the well is produced that is a characteristic feature of this mode. In continuous operation mode, low-rate wells are constantly at work, for which the number of swing balancer pumping unit must be reduced to 1, in some cases it may be necessary a lower frequency swing balancer.

The cyclic well operation mode is characterized by a number of the following disadvantages [6-8]:

− volume of produced liquid is reduced;

− the percentage of water in the liquid is increased;

− the installed power of asynchronous energy converters is increased significantly;

− the size and cost of electrical equipment is increased, that power supply system of well pad includes;

− there is a dynamic load growth in the kinematic chain links;

− there is a rapid seals wear installed on the wellhead.

Continuous mode of the liquid selection from low rate wells and the relevance of the low-speed asynchronous electromechanical energy converters development

Move to a continuous mode of low rate wells operation eliminates the mentioned above disadvantages in many respects. The implementation of continuous mode the liquid selection using asynchronous motors with low rotor shaft rotation frequency is possible if electrical parameters converter is not installed at the entrance of the asynchronous motor and the gearbox and V-belt transmission using in service at the pumping unit are not replaced.

The development of asynchronous electromechanical energy converters with a low rotation frequency of the stator magnetic field and study of their characteristics are held in the Perm National Research Polytechnic University for many years. An important result of this research was the development of improved methods for electromagnetic calculating of asynchronous electromechanical energy converters [9, 10]. Using these methods in 2004, it was realized design

3-phase asynchronous electric motor of 3 kW power, its synchronous rotor rotation frequency was 200 min^{-1} [11]. Three experimental-industrial sample of the motor on the instructions of LLC "LUKOIL-PERM" was manufactured by the holding company OJSC "Privod" (Lysva). Factory testing of electric motors and their subsequent exploitation on the oil fields of LLC "LUKOIL-PERM" showed high energy efficiency for low-speed engines. Thus, the electric efficiency coefficient of the motors was 0.73, power factor was 0.60 and energy efficiency coefficient was 0.44.

The consumption of electric energy increasing by oil and gas sector companies and electric energy costs increasing put forward as one of the priority task of further improving the low-speed asynchronous power converters, in particular the problem of increasing their energy efficiency. One of the innovative solutions of this problem is an asynchronous electric energy electromechanical converter, in which the internal reactive power compensation [12, 13].

Asynchronous electromechanical energy converter with an stator magnetizing current inner compensation differs fromcommercial asynchronous converters of available worldwide electrical companies [14, 15], so, there is two isolated from each other three-phase winding in the slots of the stator iron core, not one. One of the winding is a network and its phases are connected in the scheme "star" or the scheme "triangle" and included in the phase AC network. The second winding is a compensation. The phases of the windings are connected in the same way as the network winding. The phase beginnings of compensation winding are connected with the condensers, connected in the scheme "triangle". Wire cross section and number of coils in the sections of network and the compensation winding are different. Schemes of sections connections, of which the phases of network and the compensation winding are formed, are the same.

The calculation of the compensation chains parameters of the magnetizing current asynchronous electromechanical energy converters

For full compensation magnetizing current network winding is necessary to satisfy the following conditions:

$$F_c = F_k, \tag{2}$$

where F_c, F_k – magnetomotive force and the compensation phase network windings.

Equation (2) can be written as follows:

$$w_c I_c \sin\varphi_c = w_k I_k, \tag{3}$$

where w_c, w_k, I_c, I_k – number of coils and the phase currents active value, respectively, of network and the compensation windings; $\sin\varphi_c$ – sine of the phase angle between the voltage and current of network winding.

For the current phase active value of the compensation winding the following formula is

$$I_k = E_c \frac{w_k}{w_c} \frac{1}{x_c}, \tag{4}$$

where E_c – electromotive force of network winding phase; x_c – capacitive reactance corresponding to the connection of condensers by a scheme "star"; $E_c = 0.85 U_{fv}$; $x_c = 10^6 / 2\pi f C$, $U_{fv} = U_{lv}/3^{-2}$; U_{fv}, U_{lv} – phase and line voltage of power line.

The formula is obtained by means of simple transformations (2)-(4), establishing a quantitative relationship between the number of coils and the condensers capacitance included in the compensation winding phase, which provide the magnetizing current asynchronous motor network winding compensation with specified passport data:

$$w_k = w_c \sqrt{\frac{P_\text{n} \sin\varphi_\text{n} 10^9}{1{,}7\pi f U_\text{n}^2 \eta_\text{n} \cos\varphi_\text{n} C}}, \tag{5}$$

where P_n, U_n, η_n, $\cos\varphi_n$ – nominal values of active power, line voltage, efficiency coefficient and power factor; C – condensers capacitance.

The formula is used to calculate the number of coils in the winding network phase

$$w_c = S_n z_1 / 6a, \tag{6}$$

where S_n – slot area; z_1 – the number of slots; a – the number of parallel branches of the stator winding.

Thus, with reference to the asynchronous electromechanical energy converter 4A80A4U3-type (S_n = 60 mm^2, z_1 = 36; a = 1, P_n = 1.1 kW; U_n = 380 V; n_0 = 1500 min^{-1}, η_n = 0.75; $\cos\varphi_n$ = 0.81)

$$w_k = 1890\sqrt{1/C}. \tag{7}$$

Dependence $w_k(C)$ is shown graphically in Fig. Also there are dependences $E_k(C)$ and $I_k(C)$, the first of which is based on formula $E_k = E_c w_k / w_c$, and the second is based on the formula (4).

Work of asynchronous electromechanical energy converters with internal stator magnetizing current compensation is based on using a rotating magnetic field which is excited by a three phase system of currents flowing in contours formed by phase compensation winding and capacitors. Magnetizing current in the network winding phases is almost zero, and therefore the only active component of current and active power is consumed from the supply electrical network. Due to power factor of such engines is close to unity, and its value is saved in the working modes and in idling and at overloadings.

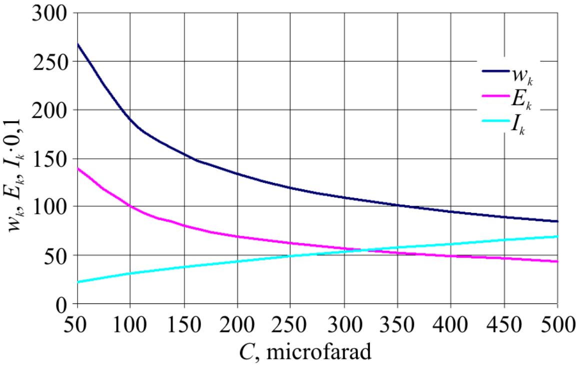

Fig. Dependence of the number of coils w_k, of electromotive force E_k and of current I_k in the compensation winding on capacity C

The invariance of the losses value in the uncompensated and compensated asynchronous electromechanical energy converters stator winding

At the same time placing in the slots of the asynchronous compensated energy converters stator additional winding does not change the electrical efficiency coefficient.

Indeed, the losses in the stator winding of the asynchronous motor without an internal compensation of the magnetizing current is calculated by the formula

$$\Delta P_1 = mI_1^2 R_1, \qquad (8)$$

where m – the number of the stator winding phases; I_1 – current; R_1 – active resistance.

The losses in the stator windings of the asynchronous motor with internal magnetizing current compensation is defined by the formula

$$\Delta P_1^* = mI_c^2 R_c + mI_k^2 R_k, \qquad (9)$$

where I_c, I_k, R_c, R_k – current and active resistance of network and the compensation phase of the stator windings.

The electrical losses components ΔP_1^* are calculated according to the following formulas:

$$mI_c^2 R_c = m(\Delta\cdot s_c)^2 \frac{w_c\cdot l_{\text{в}}}{\gamma\cdot s_c} = m\cdot\Delta^2\cdot s_c \frac{w_c\cdot l_{\text{в}}}{\gamma}, \qquad (10)$$

$$mI_k^2 R_k = m(\Delta\cdot s_k)^2\cdot \frac{w_k\cdot l_{\text{в}}}{\gamma\cdot s_k} = m\cdot\Delta^2\cdot s_k \frac{w_k\cdot l_{\text{в}}}{\gamma}, \qquad (11)$$

where Δ – current density; s_c, s_k, w_c, w_k, l_l – wire cross-section, number of coils and the coil length, respectively, of the network and compensation windings.

Therefore,

$$\Delta P_1^* = \frac{m\cdot\Delta^2\cdot l_1}{\gamma}(w_c\cdot s_c + w_k\cdot s_k). \qquad (12)$$

At the same value of the slot filling factor

$$w_c\cdot s_c + w_k\cdot s_k = w_1\cdot s_1, \qquad (13)$$

where w_1, s_1 – the number of coils and wire cross-section of the stator winding of the asynchronous electric motor with no magnetizing current internal compensation.

Then

$$\Delta P_1^* = \frac{m\cdot\Delta^2\cdot l_1}{\gamma} w_1\cdot s_1. \qquad (14)$$

Multiplying and dividing the right-hand side of this equation by the value s_1 we obtain

$$\Delta P_1^* = m(\Delta\cdot s_1)^2 \frac{w_1\cdot l_1}{\gamma\cdot s_1} = mI_1^2 R_1 = \Delta P_1. \qquad (15)$$

Therefore, power loss in the stator winding asynchronous electromechanical energy converters without compensation and with compensation winding network the magnetizing current are the same. So the electrical efficiency coefficients of these motors are the same.

Implementation of the magnetizing current internal compensation of the stator network winding of the high-speed asynchronous motor with the data presented above, allows to increase the power factor from 0.81 to 1.0, ie, 23 %. In the same way, ie, 23 % energy efficiency coefficient increases.

In the low-speed asynchronous energy converters SRPU electric drive energy efficiency of reactive magnetizing current internal compensation is incomparably higher. For example, in low-speed asynchronous energy converters, manufactured by OJSC "Privod", the implementation of the network magnetizing current stator winding internal compensation can improve power factor from 0.60 to 1.0, and the energy efficiency coefficient from 0.44 to 0.73

The use of low-speed asynchronous energy converters allows increasing the volume of the produced liquid by move to a continuous mode of low rate wells operation and significantly improve parameters of energy efficiency through the implementation of the reactive magnetizing current network the stator winding compensation.

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