SPECIAL FOR OIL FIELD BRUSHLESS SYNCHRONOUS MOTORS FOR ENERGY SAVING, STABILITY, RELIABILITY AND ECOLOGY IMPROVEMENT

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ABSTRACT

The paper deals with problems of energy losses, stability, reliability and ecology improvement in the oil field electrical networks. The sucker-rod pumps (SRP) induction motors (IM) plus power factor improving synthetic oil capacitors are working under the specific wide limits cycling moments on their shafts and also under wide voltage fluctuations in the main. It is shown that IM partial or total replacement by the special brushless synchronous motor (SBSM) is the main tool to solve these problems and up-to-date technical policy for oil field electrical engineering. Economical and quantitative estimates, that have been achieved by field experiments as well as by PC and lab hybrid computer-electrodynamic model, are presented including IM and SBSM dynamic stability analyses in conditions of supply voltage fluctuation and cyclic moment on the shafts.

INTRODUCTION

The induction motors (IM) plus matching capacitor for power factor improvement are widely used in our oil production industry as well as in the other former USSR republics as an electric drive of the so called sucker-rod pumps (SRP) for about 70 - 80% of all acting wells (SRP is the "destiny" for many years of every oil well, when production becomes poor). The analysis of their electric power consumption over last 15-20 years has shown that the consumption per ton of oil produced is growing higher [3,6]. This is due to the specific operating conditions of the oil-production electrical equipment. The electric drive of SRP operates under severe conditions resulting from the periodic variation over wide limits of its motor shaft torque, as well as from big voltage fluctuations (Fig 1a,b) in low-voltage (0.4kV) distribution networks. These fluctuations are not only due to the character of the load carried by the drive, but also due to the sharp voltage drops following the self-starts of one or group of electric motors and supply line distant short circuits. The sharply varying load on the shaft of SRP has a marked effect on the electrical characteristics of the IM used and the quality of voltage across its terminals. The IM torque varies in a cyclic manner from values close to the no-load torque (about 0.2) up to overloads of 1.5-1.8 times the rated torque with frequencies from 5 to 15 cycles per minute. The cyclic loads, phases and frequencies differ between great number of SRP and cause the voltage across the IM's terminals to fluctuate according to a very complex manner, and are impairing the power performance of the oil field electric power systems, poor as it is. Voltage fluctuations reach 15%, and short-term voltage drops due to motors self-starts and distant supply line shorts may be up to 20 % at duration of 0.2 - 0.4 sec. In this connection and due to frequent self-overturning and stoppage of induction motors, oil field electrical technicians have to use oversize motors, which cause material and electric energy losses (up to 30-40 % of the total electric power consumed by the oil field). So far as that IM matching capacitors concern more than 35 years ago our industry started to use in capacitors the synthetic oil too (freon, based on fluorine ftorol, threechlorinediphenyl, nitrosovol organic oils) instead of transformer oil. These new oil capacitors are smaller, cheaper and more reliable than the transformer oil capacitors. They are good for dry workshops and substations that have not any aggressive evaporation around. But oil fields are full of those aggressive evaporations (even around substations) especially bromine, chlorine and iodine contained underground well water that usually comes together with oil. These aggressive evaporations corrode and destroy the capacitor body and those poisonous oils leak out and bring about very well known atmospheric ecological problems.

One of the ways to reduce electric energy losses in oil production fields, to improve their networks stability, reliability and ecological situation is to use for some of SRP the so called brushless (that has not dangerous for oil industry sliding contacts) synchronous motors (BSM) equipped with the special automatic field (exciting) current control system. Inverted claw-tooth rotor motors are preferable. Operating with a power factor (cos φ=1) close to unity, such motors relieve oil field power distribution networks of reactive power, help during transients, reduce usage of oversize motors and improve the voltage quality in the networks. From the other hand during night time these IM's matching capacitors sometimes cause dangerous voltage rise in the networks and electrical power system. but SM never - it is controlling the exiting current to keep cosφ=1.

SPECIAL BRUSHLESS SYNCHRONOUS MOTOR (SBSM)

Special for oil industry brushless motor (SBSM) was elaborated by the Physico-energy Institute [2] of the Latvian Academy of Science, by the Azerbaijan State Oil Academy and Azerbijan State Oil Company "AZNEFT". The feasibility study of the SBSM application as the SRP electric drive was also made to support the first production of the SBSM. The rated power of the motors varies from 3.0 - 50kWt (the most

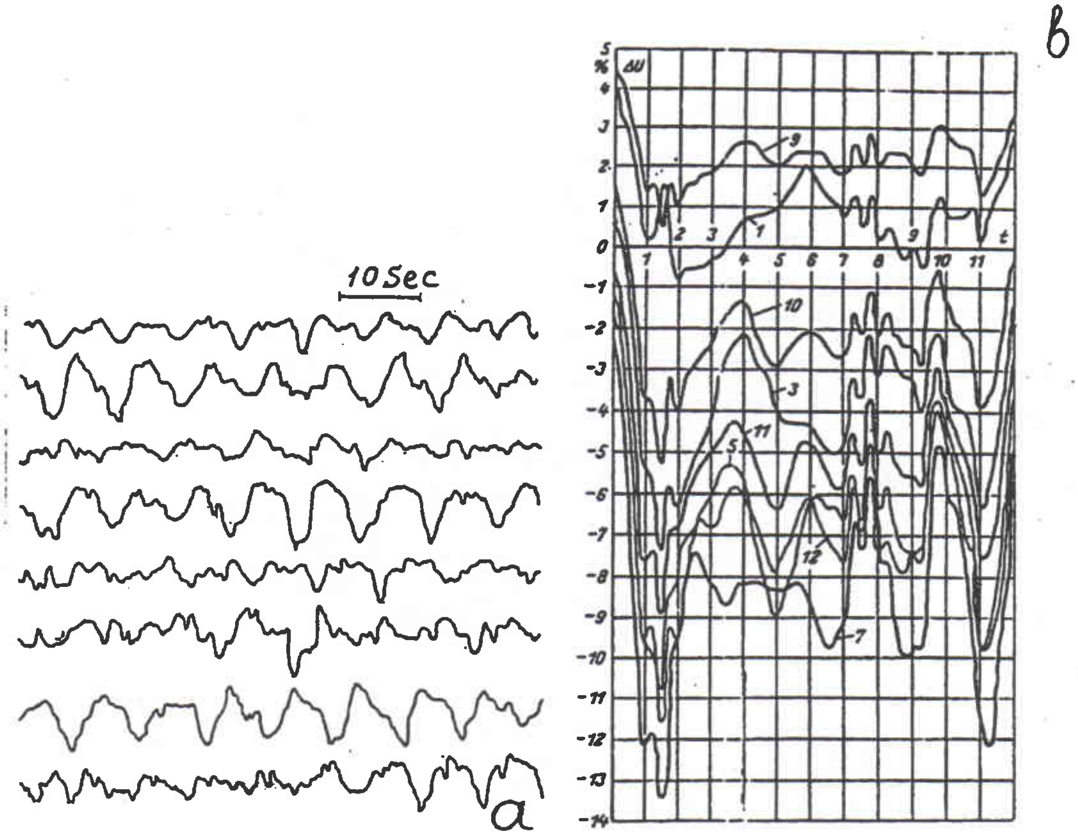


Fig.1. Oil field electrical supply networks voltages: a - field oscilogramms, b - PC calculations

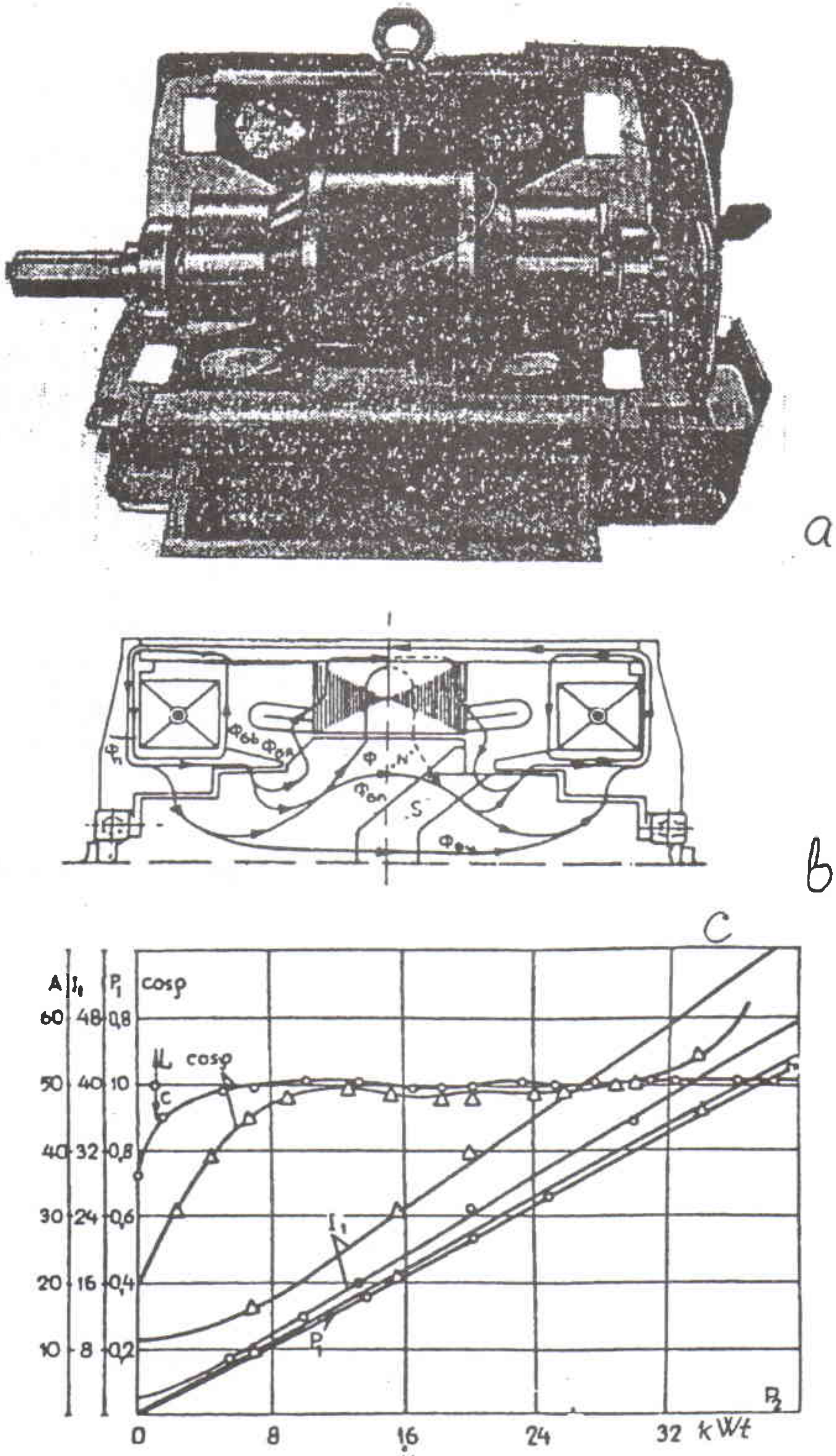


Fig.2. a - special brushes synchronous motor; b - fluxes flows and leakage's; c - main characteristics

widespread power - 20kWt). The stator of the SBSM is a bit shorter and has not any other special distinctions (Fig 2a,b) from a normal SM or IM stators. But the rotor consists of two monolith pole systems on one shaft with the special claw type trapezoidal heads on them. The squirrel cage helps to keep the poles system together and to improve the starting characteristics of the motor. The shaft is made of non-magnetic steel (or there is non-magnetic steel part cut-weld into the shaft). Two exciting coils are placed inside the back and front covers of the motor over the bearings. There is no transformer in the exciting system power supply. The power is coming directly from 380V main to controlled rectifier. This is why there are also two flat copper ring covers of the coils to reduce the induced e.m.f. Jumps in the coils during starts of the SBSM (without the ring e.m.f. can jump up to 800 - 1200V). The distance between the exciting coils and the SBSM stator is bigger than in normal SM and due this fact there are some additional flux leakages in the motor. The construction of the SBSM was made in such a way that its $\cos\varphi = 1$ for the big range of the power (torque) change (Fig 2c). The special controlled rectifier is forcing the exciting current only during big and sudden voltage drops in the main network. Due to the additional squirrel cage, mentioned before, the rated starting moment was risen from 1.2 - 1.4 to 1.8 - 2.0. The SBSM can start at any position of the pump system and the motor enters into synchronism during 3 - 5 sec. when the pulsing load moment is comming down and lower than the synchronization moment (the SBSM $M_{SYNCH} \approx 0.6 - 0.8$ during the forcing of exciting current and for normal BSM $M_{SYNCH} \approx 0.25 - 0.4$). The replacement of IM's by SBSM were made on the "AZNEFT" oil well N2884 SRP (depth 645M, 8 cycles per minute) 28kWt IM for SBSM of 20kWt and on well N2033 SRP (depth 900M, 8 cycles per minute). The cycling current came down from 21 -25A and 40 - 48.5A to 7 - 8A and 29 - 38A respectively. The power losses come down 3 times during min of the cycle and 1.3 times during max of the cycle. It was experimentally found that the rise of the exciting current from 1.4A to 2.45A gives the rise of generation of 7.8kVAR of reactive power into oil field electrical main. Taking into account the resistance of the exciting coils $R_{EXC} = 142\ \Omega$ after some calculations it was found that 0.07kWt are consumed for every 1kVAR of reactive power generation. The production price of the SBSM (for 16 - 50kWt) is 30 - 40% higher than IM of the same power. After all lab and field experiments during several years of exploitation the feasibility study was specified and corrected. The payback time of the SBSM was defined between 4 - 6 month (the common rise of main voltage, better stability and reliability of the neighbor IM's, oversize motors problem and ecology were even not taken into account).

VOLTAGE FLUCTUATION INFLUENCE ON STABILITY

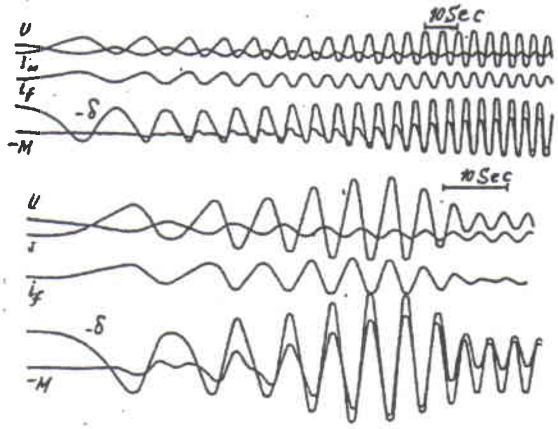
It is very difficult to use digital computer for these studies due to protracted real time of investigation (several minutes) and very stiff character of the IM and SBSM full equation. This is why the named analyses were made by the help [1,3,4,7] of the hybrid-computer and lab electro-dynamic model with real but small power IM and SBSM. The idea of the approach to solution of the problem was the following: it was accepted as an evident assumption that the main influence on the stability of IM and SBSM (with constant exciting current) ought to exert in the first place - the low frequency harmonics equals to the frequency of the shaft moment oscillation (0.1 - 0.5Hz), especially the contra phase oscillations, and in the second place - the relatively high frequency harmonics (2 - 20Hz), equal to the electro-mechanical resonance frequencies of IM or SBSM shaft systems. Suppose that voltage is oscillating according to:

$U = U_{MIN} + 0.5(U_{MAX} - U_{MIN})*[1+\cos(\Omega_U t + \beta_U)]$.

For the first case the frequency of the voltage fluctuation Ω_U is equal to Ω_M - the frequency of the shaft moment oscillation and $\beta_U = 0°, \pm 90°$ and $180°$ (for four fixed voltage deviations $\Delta U = U_{MAX} - U_{MIN} =$ 0; 5; 15 and 20%). The moment on the shaft of the drive

$M = M_{MIN} + 0.5(M_{MAX} - M_{MIN})*(1 - \cos\Omega_M t)$

was slowly weighted by rising only M_{MAX} ($M_{MIN} =$ const $\approx 0.15 - 0.2$) up to stability limit. The last value of M_{MAX} was taken as the limit result for comparison of the IM and SBSM stability factor. On the base of large number of the investigated variants it was found that every 1% of this low frequency voltage pulsation brings down the IM dynamic stability for about 1.75 - 2.5% and for the SBSM for about 2 - 3%. As we can see the figures are almost the same and from dynamic stability point of view both IM and SBSM are almost equal under this low frequency voltage pulsation. In the second case first of all was approximately found the resonance frequency (Fig 3) of the IM and SBSM electric drives. Due to relatively high value this frequency of voltage pulsation (2 - 20Hz) it is evidently clear that the stability of the IM and SBSM may be broken down during the moment of the passing maximum torque on their shafts. From this point of view for every fixed value of $M = 1.2$; 1.4; 1.6 and 1.8 the value of ΔU (under $U_{MAX} = U_{NOM} = 380V$) was slowly rising from 0 to the limit of the motor stability (i.e. U_{MIN} was reducing from $U_{MIN} = U_{MAX}$ to the limit of stability) and the last value of U_{MIN} (or $\Delta U = U_{MAX} - U_{MIN}$) was taken as the limit result for comparison of the IM and SBSM dynamic stability. Similarly, on the base of the large number of investigated variants it was found that every 1% of this high (resonance) frequency voltage pulsation brings down the IM dynamic stability approximately



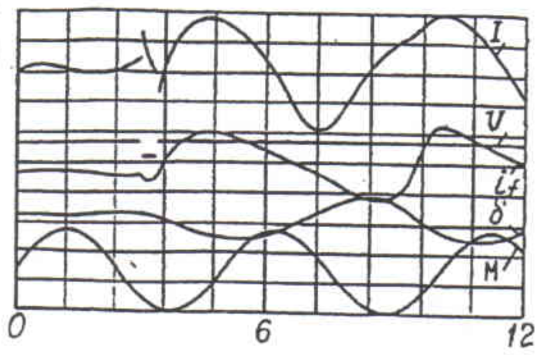


Fig.3.a) Electromechanical resonance in SRP drive system b) PC modeling results

by 1.5 - 2% and for the SBSM by 2.1 - 2.4%. And similarly, we can see that the figures are almost the same and from dynamic stability point of view both IM and SBSM are almost equal under this high (resonance) frequency voltage pulsation. But the Fourier analysis of the several waves of the real voltage fluctuation (Fig 1) have shown that the amplitudes of these high frequency harmonics (higher than 2Hz) are less than 0.5% of ΔU and due to this fact the stability losses will not be expected more than 1 - 1.2% for both motors and can be neglected. The SBSM was also equipped by special exciting current control (forcing) system to support the voltage in the main and to rise SBSM stability to higher level than the IM especially for short (0.2 - 0.4 sec.) abrupt voltage drops. Here, in the last case, was more convenient to use PC for modeling.

MODELING ON PC ABRUPT VOLTAGE DROP MOTORS STABILITY

To substantiate the possibility of replacing some of the IM in a given oil field by SBSM, both at the design stage and in the course of pilot recovery, it is necessary to develop a digital model of IM and SBSM as SRP electric drive intended for multiple-variant studies into the relatively stiff dynamic system. To provide for the normal operation of SBSM in SRP, one should investigate the reserves of stability of the motor in conditions of abrupt and substantial supply voltage drops and cyclic torque variations. There are a number of methods that can be used to study the static and dynamic stability of electromechanical systems. But where the electric motor drive to be analyzed operates in conditions of simultaneously varying load and supply voltage, these methods prove to be difficult to apply. The operation stability of these electric drives can effectively be analyzed by the digital structural modeling technique. This technique is as follows. The complex object to be analyzed is broken up into individual structural elements, which in turn are implemented in the form of digital blocks combined into a digital model in accordance with the structure of the object. As will be recalled, the synchronous motor is described by the system of the well known Park equations (omitted here), which takes accounts of the automatic field current controller, mechanical part, and supply line. To implement the digital model of the electric drive for a SRP use was made of the Wide-Access Modeling System [5] - the Russian prototype of Matlab+Simuling. Our studies have shown that the reserve of stability of a synchronous motor decreases with the increasing torque variation frequency and distance from the power supply center. But even for high-speed SRP SBSM motors (Ω_M=0.35 Hz), distant from the power supply center and operating at 20% supply voltage fluctuations occurring at a frequency close to Ω_M, the reserve of stability is no less than 15 %, which is better than that IM of SRP. One of criteria for efficient operation of sucker-rod pump driving systems is their endurance, or the ability to withstand short-term distant short circuits in the oil-field power distribution network. The new electric drive system suggested is considered to be enduring if it continues to operate stable after 20% supply voltage drop lasting for 0.4 s. In this connection, we have conducted, using the digital model proposed, numerous investigations into the stability of a synchronous motor operating in conditions of sudden supply voltage drops. The results have shown that the SBSM drive subject to cyclic torque variations remain stable even in the case of 30% supply voltage drop lasting for 0.4-0.7 sec. and even longer for some cyclic motor torque phases, but IM less than 0.3 sec under the same conditions.

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