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# METHODS FOR IMPROVING THE ENERGY EFFICIENCY OF WELL ROD PUMP UNITS

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***Abstract*—**The concept of oil production energy efficiency improvement of good rod pumps by utilization of kinetic energy of the downward moving rod in capacitor bank is proposed. A mathematical model of the system is developed. Criteria of reduction of the peak values of current, consuming power and elimination of oscillations are obtained. It is shown that the developed system is capable of reducing the consumption of current twice and the peak power by three times. Thus it is possible to reduce operational and capital costs by reducing the cross-section of the feeder cables and decreasing the power of input transformers and diesel generator set if autonomous feeding of pumping units is used.

***Keywords*—**Sucker rod pump, rack-and-pinion drive, linear rod pump, oil production plants, energy efficiency, electric drive

## I. INTRODUCTION

A difficult world hydrocarbon market situation with decreasing oil prices have forced oil development companies to search for the methods of oil extraction's prime cost reduction, Andreev and Urazakov [1]. The ratio of energy consumption W to calculated liquid volume $Q_l$ Burmakin [2] is one of the criteria of energy efficiency estimation:

$$W_{\text{pu}} = \frac{W}{Q_l} \qquad (1)$$

The expression (1) shows that the reduction of energy consumption and the increase of extracted liquid's volume are main ways of oil extraction's energy efficiency increase. The development of oil fields with low production benches and the depletion of oil fields by entering the final extraction phase with the use of low-flow well sites are common conditions for nowadays Russian Petroleum Industry.

Cluster pump stations are often used at marginal oil fields with the purpose of some increase of petroleum development volumes and as a result reduction of economic expense. The usage of cluster pump stations itself is not an answer to the energy efficiency problem because of the widespread employment of sucker rod pumps (SRP) with beam pumping units with and without horsehead for the well sites development. It is well-known, Lysenko and Grajfer [3], Artykaeva [4] and Silash [5], that these pumps are of little use for marginal oil field extraction because of their unsatisfactory weight-size parameters, low reliability, low efficiency, necessary foundation construction with consequential essential financial and time spends on well site installation and complicated driver adjustment in a part of polished rod's velocity change and number of double strokes. Thus the increase in the energy efficiency of marginal well sites extraction becomes a primary proposition and is directly connected to the energy usage level reduction. The present paper describes such reduction methods, scored and analyzed in the project, sponsored by the Ministry of Education and Science of Russian Federation.

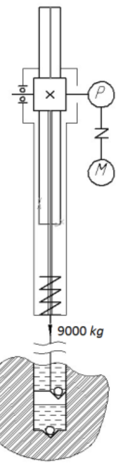


Fig. 1. Linear rod pump drive kinematic diagram

## II. ANALYSIS OF ELECTRIC ENERGY CONSUMPTION REDUCTION METHODS

Electric energy consumption of the drive can be calculated as (2):

$$P_1 = m \cdot U_{ph} I_{ph} \cos \quad , \qquad (2)$$

where:
$m$ is the number of power supply phases;
$U_f$ is the RMS phase voltage, V;

$I_f$ is the RMS phase current, A;
*cosφ* is the power factor.

As it is seen from (5), power factor significantly affects on current consumption from the power supply. As it is known Ivanovskij [6], Hakimyanov [7] and Gimatudinova, Andriasov, Mishchenko and Petrov [8], Arhipov, V.I.Popov and I.V.Popov [9], patent № 98111569/06 [10] and Valovskij, Ahunov, Manko, Fedoseenko [11] there are considerable oscillations of the consuming power during the sucker rod pumps operation. Also, there is the data, Artykaeva [4] that the power consumption of induction motor (IM) during the pump cycle could vary up to 7 times. In view of using squirrel-cage induction motor (ISCM) as a driving motor, such difference in power consumption leads to sufficient surges of current in the power grid, and also it leads to acute alteration of motor power factor and its thermal and mechanical overloads.

This fact causes selection of the motors with bigger rated power. As a result of the average values of motor efficiency and the power factor decrease that leads to additional energy losses in feeder cables caused by reactive currents. With the use of reverse drives, such as linear rod pump or chain rod pump, the need of reverse of the motor also leads to additional losses in the motor and in the switching and control equipment during the motor start. This problem could be solved by means of application of frequency converters, which could execute energy-efficient algorithms for motor driving. Besides the frequency control, it is possible to improve the energy performance of the drive by means of the kinetic energy of moving down rod during the phase of petroleum elevation, Valovskij, Ahunov, Manko, Fedoseenko [11] and patent US11/761.484 12.06.2007 [12]. In the present paper, the following approach is implemented:

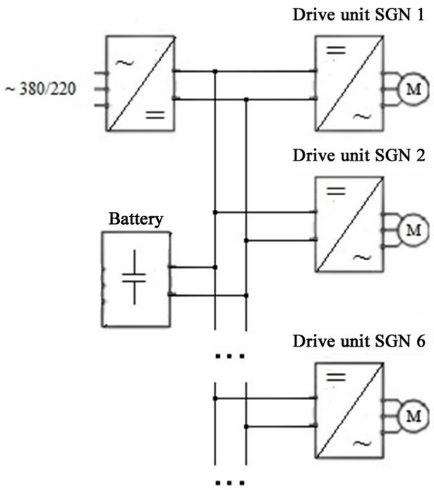


Fig. 2. Structural chart of system consisted of SRPU with linear rod pump drive in cluster development method

While the rod moves down the driving motor switches to generator mode. In cluster development drives of sucker rod pumping unit (SRPU) are connected via DC link of the control system. A capacitor bank with a large capacity is also connected to the DC link. As a result, the kinetic energy of the rod gets stored in the capacitor bank. Stored energy is used in the phase of petroleum elevation with the help of the microprocessor control system so that electric energy will be saved. The structural chart of the developed system is presented in Fig. 2.

Let us consider a mathematical model of this system. In the simulation the following terms and simplifications were admitted:

*1). Losses in the good rod pump valve from the viscous forces, friction forces between the rods and the shaft of pumping and compressive pipes, dynamic forces and vibrations are negligible.*

*2). Input converter and the well rod pump frequency converter are modeled as the ideal controllable current sources.*

*3). Dependence of real power from time, t in well sucker-rod pump unit (WSRPU) has the form:*

$$P_n(t) = P_{mn} \cdot \sin\left(2\pi \frac{t}{T_n} + {}_{n0}\right) + P_{0n}\,, \qquad (3)$$

*where:*
$P_{mn}$ *– amplitude of the alternating component of power,* $P_{on}$ *– constant component of power,* $T_n$ *– pumping period,* $\varphi_n$ *– initial phase.*

*4). Connection of WSRPU is performed only after full charge of capacitors bank to the 560 VDC (output rectifier voltage connected to the 380/220 VAC grid)*

The aim of the calculation is to select the value of active power consumed from the grid to provide the constant average value of the capacitor voltage during the period (if the specified voltage rises the power is excessive and utilizes for the bank charging, and in case of voltage drop the power is insufficient and causes the bank discharge). The design diagram is shown in Fig. 3.

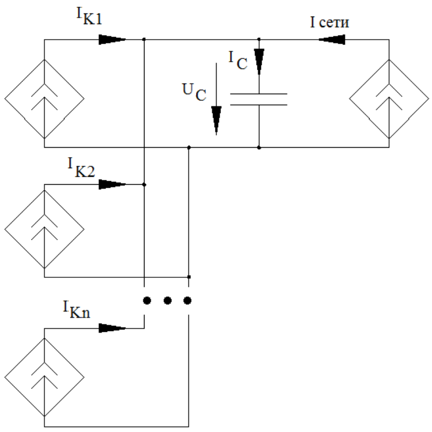


Fig. 3. The design diagram, $U_C$ - capacitors battery voltage, $I_{grid}$ – converter output current consumed from the grid, $I_c$ – charge/discharge current of the capacitors battery, $I_{K1} \ldots I_{кn}$ - current consumed by the *n*-th WSRPU drive (input current of the inverter of the frequency converter).

The current consumed from the grid is calculated as (4)

$$I_{grid} = \frac{P_{grid}}{U_C(t)}, \tag{4}$$

where $P_{grid}$ is the power consumed from the grid.

The current consumed by the $n$-th WSRPU drive is calculated as (5)

$$I_{Kn}(t) = \frac{P_n(t)}{U_C(t)} \tag{5}$$

The differential equation describing the capacitor's voltage alteration after connection of N drives is as in (6):

$$C\frac{dU_C(t)}{dt} = \frac{P_{grid}}{U_C(t)} - \sum_{n=1}^{N}\frac{P_n(t)}{U_C(t)} = \frac{P_{grid}}{U_C(t)} - \sum_{n=1}^{N}\frac{P_{0n}}{U_C(t)} - \sum_{n=1}^{N}\frac{P_m \sin(2\pi\frac{t}{T_n} + {}_{on})}{U_C(t)}, \tag{6}$$

Since the plugin of the WSRPU drives is performed after the full battery charging the initial condition is as in (7)

$$U_C(t)\big|_{t=0} = U_{K0}, \tag{7}$$

where $U_{K0}$ is the nominal capacitor bank voltage at the end of the charging.

The solution of (6) considering (7) after transformations could be written as (8)

$$U_C(t) = \sqrt{U_{K0}{}^2 + \frac{2\left(P_{grid} - \sum_{n=1}^{N} P_{0n}\right)}{C}t - \sum_{n=1}^{N}\frac{2T_n \cdot P_{mn}}{\pi C}\sin\left(\frac{\pi t}{T_n} + {}_n\right)\sin\left(\frac{\pi t}{T_n}\right)}, \tag{8}$$

From (9) it is following that to provide the constant average voltage it is necessary to satisfy the equation

$$P_{grid} = \sum_{n=1}^{N} P_{0n}. \tag{9}$$

The minimum voltage of the capacitor bank, considering (10) depends on the bank capacity, the pumping period, the periodic component of the consumed power and is determined by the expression:

$$U_{C\min} = \sqrt{U_{K0}{}^2 - \sum_{n=1}^{N}\frac{2T_n \cdot P_{mn}}{\pi C}}. \tag{10}$$

The peak current consumed from the grid is calculated as (11)

$$I_{grid_{max}} = \frac{P_{grid}}{U_{C\min}} = \frac{P_{grid}}{\sqrt{U_{K0}{}^2 - \sum_{n=1}^{N}\frac{2T_n \cdot P_{mn}}{\pi C}}} \tag{11}$$

Calculations performed for the case of the single WSRPU drive 20 kW rated capable to generate 7.5 kW when driving down with the pumping period of 12 s showed that connection of capacitor tank with the total capacity of 3F allows to reduce the power consumption from the maximal value of 20 kW to the 6.25 kW, i.e. triple decrease. The power surges are eliminated in this case. The peak values of the current consumed from the grid decreased from 40 to 18 A, i.e. double decrease. The minimal voltage of capacitor bank is 527.8 V, and the maximal value of the grid current is 11.8 A. The calculated current and voltage plots are given in Fig. 4.

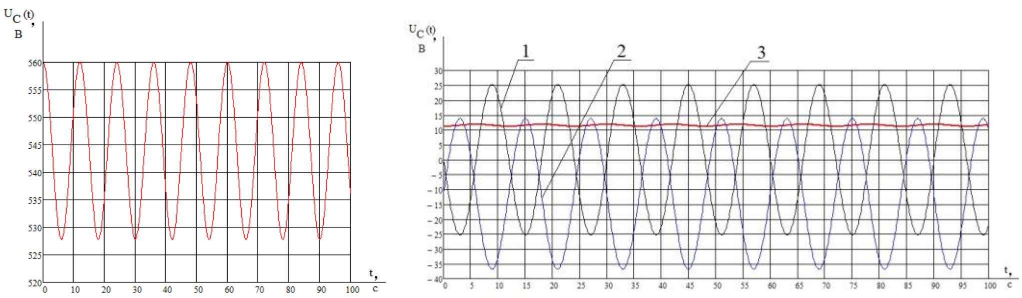


Fig. 4. Results of the calculation a) Capacitor bank voltage b) Calculated currents: 1. charging/discharging capacitor bank current; 2. pump unit current (input current of inverter); 3. Grid current (converter output current)

This design diagram was also investigated in Matlab-Simulink. The results matched the results above and are mot presented in the paper. Analogic calculations performed for two WSRPU drives showed that the application of capacity bank and regulation of pump rate and initial rod position also allows to decrease the total power consumption during the cluster development and to eliminate consuming power surges.

The decrease of the input current and consuming power allows to reduce exploitation expenses and the power consumption of the system in comparison with the single drive units with the unique control system and also to reduce expenses for the feeder cables.

The absence of the sharp current and power surges facilitates conditions of operation of the substation transformer or of the diesel generator in case of the autonomous electrical power system. The rated power of the drives and accessories could be reduced that decrease the capital and exploitation expenditures.

## III. Conclusion

The principal diagram of the connection of the WSRPU drives is proposed. The mathematical model of the system describes the usage of the kinetic energy of the moving down rod. Criteria of the consuming power and current reduction of the system are developed.

The modeling of the single WSRPU with the system of storage and utilization of the moving down rod is performed. It is shown that implementation of such system provides a considerable reduction of the current surges consumed from the grid and the triple reduction of the peak active power and elimination of the consuming power oscillations.

Implementation of the linear rod pump drives with the kinetic energy storage system allows to reduce exploitation expenses and the power consumption of the system in comparison with the single drive units with unique control system and also to reduce operational and capital costs by reducing the cross-section of the feeder cables and using of substation transformers or diesel generators of fewer rates power.

## References

[1] V.V. Andreev, K.R. Urazakov, Oil production handbook, edited by K.R.Urazakov, Moscow, OOO Nedra Biznes-tsentr, 2000. pp. 374.

[2] A.M. Burmakin, Low-speed curved-stator induction motor for sucker rod pumps of low productive oil wells, Electromechanical and electromagnetic energy converters and controllable electromechanical systems, Proceedings of 4th International scientific and engineering workshop, Yekaterinburg, URFU, 2011. pp. 344-348.

[3] V.D. Lysenko, V.I. Grajfer, Development of low-productive oil fields, [Razrabotka maloproduktivnyh neftyanyh mestorozhdenij], Moscow, OOO Nedra-biznestsentr, 2001, pp. 562.

[4] E.M. Artykaeva, Energy efficient electrical equipment of oil-producing plants with plunger submersible pump; Ph.D. thesis, [Energo resurso sberega yushchee elektro oborudovanie nefted obyvashchih ustanovok s plunzhernym pogruzhnym nasosom, avtoreferat dissertatsii kandidata tekhnicheskih nauk], Cheboksary Izdatelstvo FGBOU VPO CHGU, 2012, pp. 21.

[5] A.P. Silash, Extraction and Transportation of Oil and Gas, vol. I, translation from English, [Dobycha i transport nefti i gaza], Moscow, Nedra, 1980, pp. 264.

[6] V.N. Ivanovskij, Energetics of oil extraction, principal trends in energy consumption optimization, [Energetika dobychi nefti, osnovnye napravleniya optimizatsii energopotrebleniya]. Inzhenernaya praktika, No. 6, 2011, pp.18-26

[7] M.I. Hakimyanov, Per unit electrical energy consumption during the oil extraction by submersible pumps, [Udelnyj raskhod elektroenergii pri dobyche nefti shtangovymi glubinnonasosnymi ustanovkami], Vestnik UGATU, Vol. 18, No. 2, 2014, pp. 54-60

[8] Sh.K. Gimatudinova, R.S.Andriasov, I.T.Mishchenko, A.I.Petrov, Handbook on planning and exploitation of oil fields. Oil extraction, [Spravochnoe rukovodstvo po proektirovaniyu razrabotki i ekspluatatsii neftyanyh mestorozhdenij], Dobycha nefti, Moscow, Nedra, 1983, 455 p.

[9] K.I. Arhipov, V.I.Popov, I.V.Popov, Sucker rod pumps handbook, [Spravochnik po stankam-kachalkam]., Almetevsk Izdatelstvo AO Tatneft, 2000, 146 p.

[10] Patent RF [Patent of Russian Federation] № 98111569/06, 10.06.1998

[11] V.M. Valovskij, R.M. Ahunov, M.I. Manko, N.V. Fedoseenko, Well rod pump drive, [Privod skvazhinnogo shtangovogo nasosa], patent Rossii №2150607б opublikovan BI №16 10.06.2000.

[12] Patent US11/761.484 12.06.2007 T.L. Beck, R.G. Anderson, R.G. Peterson, M.A. D. Benjamin, J. Gregory, R.G. Peterson Linear Rod Pump Apparatus and Method // Patent US US20070286750 A1 published 13.12.2007