Results of mathematical modeling of the mud pump electric drive operation with the compensation unit in the circuit

T V Tabachnikova and L V Shvetskova

Almetyevsk State Oil Institute, 2 Lenin Street, Almetyevsk, 423452, Russia
E-mail: tvtab@mail.ru

Abstract. The mathematical model was developed for the mud pump electric drive with an individual compensation unit in a bypass circuit, which allows simulating the electric drive operation during the start and in steady-state modes with and without regard to the individual compensation unit. The mathematical model of the electric drive of the mud pump was developed with the aim of increasing the reliability and continuity of the drilling rig technological process in case of failure of the frequency-controlled converter of the electric drive. The use of the electric drive parameters given in relative units in a mathematical model allows replicating the obtained simulation results for other modifications of the pump electric drive. It is proved that when an individual compensating unit is included in the electric drive circuit, it reduces the loss of active power in the cable line and overhead line, and helps to increase the efficiency of the mud pump. The simulation results showed the boundary parameters of the dependent and independent variable parameters of the distribution electric network, at which the start-up of the electric drive of the mud pump is completed successfully.

1. Introduction

This article discusses the MDU (mobile drilling unit) 3000, which is used for rotary and downhole motor drilling. To achieve optimal mud pump operation, the developed power must remain constant and equal to the nominal power. The authors have developed a mathematical model of the mud pump electric drive to analyze the steady-state operation modes and start-up modes. To check the validity of the results obtained using the proposed mathematical model, the most commonly used pump locking device with a nominal power of 1000 kW is assumed as an electric drive. Given that the per-unit parameters of pump locking devices with different capacities are close to each other, the simulation results obtained can be valid for other modifications of this series.

Figure 1 shows a schematic diagram of the drilling rig electrical complex with the following reference designations: \( L \) – the length of a 6 kV outgoing circuit up to the rig, \( l_1 \) – a section of the aerial line from the supply feeder to the rig, \( T_1 \) – a step-down transformer in the package transformer substation, \( P + jQ \) – the drilling rig equivalent load, \( l_2 \) – a high voltage cable line supplying the electric drive of the drilling rig electric pump unit, a shunt compensation unit (SCU 1) is an individual unit designed for compensating reactive power of a 1000 kW induction motor (IM).

The mud pump electric drive is connected to the power supply through a high-voltage frequency converter, however, Figure 1 shows a schematic diagram of the mud pump electrical complex for the scenario, in which the drive is connected directly to the mains.
2. Problem statement

Currently, a variable frequency drive for mud pumps is used, which allows reducing the number of piston replacements in the course of drilling. However, frequency-controlled converter failures occur from time to time, which entails losses. To avoid frequent stops of the mud pump occurring due to the failure of the high-voltage frequency-controlled converter and in order to improve the operation process reliability and continuity, it is proposed to introduce a bypass (Figure 2), that is, to arrange a direct connection of the pump unit electric drive to the power source. We propose a configuration assuming an electric drive with an individual compensation unit, which will reduce the loss of true power in the cable line and aerial line, and also contribute to the mud pump efficiency improvement. When introducing an individual compensation unit, there will be a need to connect a discharge device in order to discharge the reactive power in the system.

![Figure 1. Schematic diagram of the drilling rig electrical complex](image)

![Figure 2. Mud pump electric drive power supply diagram](image)
3. Theory

Based on the schematic diagram (Figure 1) and the equivalent circuit of the drilling rig electrical complex (Figure 3) connected at the node (A) at the end of the outgoing line, mathematical and simulation models of this complex were developed. The mathematical model includes the following parameters: a long aerial line section, the node compensation unit SCU2, a step-down transformer \( T_1 \), equivalent load \( P+jQ \), a step-up transformer \( T_2 \), a mud pump unit, and an individual compensation unit SCU1. The mathematical model of the mud pump electrical complex allows simultaneous simulation of the operation in steady-state and transient modes [1, 2, 3].

![Figure 3. Equivalent circuit of the mud pump electrical complex connected at the node (A) at the end of the outgoing line](image)

A system of analytical dependencies (1 – 5) has been obtained based on the equivalent circuit:

\[
\begin{align*}
    u_{22}(t) &= R_3 i_{02} + L_3 \frac{di_{02}}{dt} + u_{c1}; \\
    i_{02} &= i_1 + i_{c1}; \\
    i_1 &= i_{02} - C_{c1} \frac{du_{c1}}{dt}; \\
    u_{c1}(t) &= R_1 i_1 + \frac{d\psi_1}{dt}; \\
    0 &= i_2 R'_2 + \frac{d\psi_2}{dt},
\end{align*}
\]

where \( u_{22} \) and \( i_{02} \) are the input voltage and current in the downhole motor power cable line at the well entry; \( R_3 \) and \( L_3 \) – true resistance and inductance of the downhole motor power cable line; \( i_{c1} \) – current at SCU1 (condenser \( C_1 \) ) terminals; \( u_{c1} \) – voltage at SCU1 terminals; \( i_1 \) – stator current, \( i_2 \) – rotor current; \( R_1 \) – true stator winding resistance; \( R'_2 \) – true stator winding resistance normalised to the stator winding [4, 5].

Let us express the stator and rotor winding currents \( i_1 \) and \( i_2 \) and through the stator \( \psi_1 = i_1 L_1 + i_2 L_m \) and rotor \( \psi_2 = i_2 L_2 + i_1 L_m \) winding flux linkages, respectively, where \( L_1 = L_{a1} + L_m \), \( L_2 = L_{a2} + L_m \) are the total stator and rotor winding inductance values.

\[
\begin{align*}
    i_1 &= \frac{\psi_1 - \psi_2}{L_1 - L_m} \\
    i_2 &= \frac{\psi_2 - \psi_1}{L_2} \\
    \text{or} \quad i_1 &= \frac{\psi_1 - \psi_2}{L_1} - \frac{k_2}{L_1} \psi_2 \\
    \text{or} \quad i_2 &= \frac{\psi_2 - \psi_1}{L_2} - \frac{k_1}{L_2} \psi_1.
\end{align*}
\]
\[ i_2 = \frac{\psi_2 - \psi_1 L_m / L_1}{L_2 - L_m^2 / L_1} \quad \text{or} \quad i_2 = \frac{\psi_2 - \psi_1 k_1}{L_2' - L_2} = \frac{1}{L_2'} \psi_2 - \frac{k_1}{L_2'} \psi_1, \]

where \( k_1 = \frac{L_m}{L_1} \) is the coupling factor for stator; \( k_2 = \frac{L_m}{L_2} \) — coupling factor for rotor;

\( L'_1 = L_4 - \frac{L_m^2}{L_2} \) — transient inductance of the stator winding in case of a short-circuit rotor winding;

\( L'_2 = L_2 - \frac{L_m^2}{L_4} \) — transient inductance of the rotor winding in case of a short-circuit starter winding.

Let us apply the stator (6) and rotor (7) current values, expressed in terms of flux linkages, to the stator current and induction machine voltage equations (3-5), then we get:

\[ \frac{\psi_1 - \psi_2 k_2}{L'_1} = i_{02} - C_1 \frac{du_{c1}}{dt}, \quad \text{then} \quad i_{02} = \frac{1}{L'_1} \psi_1 - \frac{k_2}{L'_1} \psi_2 + C_1 \frac{du_{c1}}{dt}; \]

\[ u_{c1} = \frac{\psi_1 - \psi_2 k_2}{L'_1} \cdot R_1 + \frac{d \psi_1}{dt}; \quad u_{c1} = \frac{R_1}{L'_1} \psi_1 - \frac{R_1}{L'_2} \psi_2 + \frac{d \psi_1}{dt}; \]

\[ d = \frac{\psi_2 - \psi_1 k_2}{L'_2} \cdot R_2 + \frac{d \psi_2}{dt}; \quad d = \frac{R_2}{L'_2} \psi_2 - \frac{R_2}{L'_2} \psi_1 + \frac{d \psi_2}{dt}. \]

Putting formulas (8—10) into the system of algebraic and differential equations (1—5), we get:

\[ u_{22}(t) = R_3 i_{02} + L_0 \frac{di_{02}}{dt} + u_{c1}; \]

\[ i_{02} = i_1 + i_{c1}; \]

\[ i_{02} = \frac{1}{L'_1} \psi_1 - \frac{k_2}{L'_1} \psi_2 + C_1 \frac{du_{c1}}{dt}; \]

\[ u_{c1} = \frac{R_1}{L'_1} \psi_1 - \frac{R_1}{L'_2} \psi_2 + \frac{d \psi_1}{dt}; \]

\[ d = \frac{R_2}{L'_2} \psi_2 - \frac{k_2}{L'_2} \psi_1 + \frac{d \psi_2}{dt}. \]

Let us differentiate instantaneous current and voltage values:

\[ u(t)_{22} = U_m \sin(\omega_0 t + \psi_u) \quad \text{— instantaneous voltage at the well entry;} \]

\[ i(t)_{02} = l_m \sin(\omega_0 t + \psi_u) \quad \text{— instantaneous current of the pump locking device power cable;} \]

\[ u(t)_{c1} = U_m \sin(\omega_0 t + \psi_u) \quad \text{— instantaneous voltage at the UPEC1 terminals.} \]

Next, the instantaneous values of currents and voltages are differentiated:

\[ \frac{d}{dt} u(t)_{22} = \frac{d}{dt} \left( U_m \sin(\omega_0 t + \psi_u) \right) = \frac{d}{dt} U_{22} + j \omega_0 U_{22}; \]

\[ \frac{d}{dt} i(t)_{02} = \frac{d}{dt} \left( l_m \sin(\omega_0 t + \psi_u) \right) = \frac{d}{dt} i_{02} + j \omega_0 i_{02}; \]
\[
\frac{d}{dt} u(t)_{c1} = \frac{d}{dt} \left( U_m \sin(\omega_0 t + \psi_m) \right) = \frac{d}{dt} \tilde{U}_{c1} + j\omega_0 \tilde{U}_{c1}; \\
\frac{d\psi_1}{dt} = \frac{d}{dt} \tilde{\psi}_1 + j\omega_0 \tilde{\psi}_1; \\
\frac{d\psi_2}{dt} = \frac{d}{dt} \tilde{\psi}_2 + j(\omega_0 - \omega_2) \tilde{\psi}_2. 
\]

The obtained values in the complex form are then applied to the original system of equations:

\[
\tilde{U}_{c2} = R_{13} I_{c2} + L_{13} \left( \frac{d}{dt} I_{c2} + j\omega_0 I_{c2} \right) + \tilde{U}_{c1}; \\
\tilde{I}_{c2} = \frac{1}{L_1} \tilde{\psi}_1 - \frac{k_2}{L_1} \tilde{\psi}_2 + C_I \left( \frac{d}{dt} \tilde{U}_{c1} + j\omega_0 \tilde{U}_{c1} \right); \\
\tilde{U}_{c1} = \frac{R_1}{L_1} \tilde{\psi}_1 - \frac{k_2}{L_1} \tilde{\psi}_2 + \frac{d}{dt} \tilde{\psi}_1 + j\omega_0 \tilde{\psi}_1; \\
0 = \frac{R_2}{L_2} \tilde{\psi}_2 - k_1 \frac{R_1}{L_2} \tilde{\psi}_1 + \frac{d}{dt} \tilde{\psi}_2 + j(\omega_0 - \omega_2) \tilde{\psi}_2, 
\]

where \( \omega_2 \) is the rotation frequency of the pump locking device rotor; let us transform

\[
(\omega_0 - \omega_2) = \omega_0 \omega_{02} - \text{the product of the slip and the electric network cyclic frequency and denote}
\]

\[
\frac{d}{dt} = p - \text{the symbol of differentiation.}
\]

To simplify the recording format, the vector sign in the system of equations (21-24) can be omitted.

Using the transformation and notation, let us put down this system in the rotating coordinates system with synchronous rotation velocity \( \omega_0 \) :

\[
U_{22} = R_{13} I_{c2} + L_{13} \left( pI_{c2} + j\omega_0 I_{c2} \right) + U_{c1}; \\
I_{c2} = \frac{1}{L_1} \psi_1 - \frac{k_2}{L_1} \psi_2 + C_I \left( pU_{c1} + j\omega_0 U_{c1} \right); \\
U_{c1} = \frac{R_1}{L_1} \psi_1 - \frac{k_2}{L_1} \psi_2 + \frac{d}{dt} \psi_1 + j\omega_0 \psi_1; \\
0 = \frac{R_2}{L_2} \psi_2 - k_1 \frac{R_1}{L_2} \psi_1 + \frac{d}{dt} \psi_2 + j(\omega_0 - \omega_2) \psi_2. 
\]

Projections of the initial parameter vectors on the \( x \) and \( y \) axes are obtained by asserting:

\[
U_{22} = U_{22x}; \\
I_{c2} = I_{c2x} + jI_{c2y}; \\
\psi_1 = \psi_{1x} + j\psi_{1y}; \\
\psi_2 = \psi_{2x} + j\psi_{2y}; \\
U_{c1} = U_{c1x} + jU_{c1y}. 
\]

Let us put their projections into the system of equations:
\[ U_{22,x} = R_{i1} I_{02,x} + R_{i2} I_{02,y} + L_{i1} \frac{\alpha_0}{\omega_0} pI_{02,x} + L_{i2} \frac{\alpha_0}{\omega_0} pI_{02,y} + j \omega_0 L_{i1} I_{02,y} + j j \omega_0 L_{i2} I_{02,y} + U_{c1,x} + j U_{c1,y}; \]

\[ I_{02,x} + j I_{02,y} = \frac{1}{L_1} \psi_{1,x} + \frac{1}{L_1} j \psi_{1,y} - \frac{k_2}{L_1} \psi_{2,x} - \frac{k_2}{L_1} j \psi_{2,y} + \]

\[ + C_1 \frac{\alpha_0}{\alpha_0} pU_{c1,x} + C_1 \frac{\alpha_0}{\alpha_0} pI_{c1,y} + j C_1 \omega_0 U_{c1,x} + j j C_1 \omega_0 U_{c1,y}; \]

\[ U_{c1,x} + j U_{c1,y} = \frac{R_1}{L_1} \psi_{1,x} + \frac{R_1}{L_1} j \psi_{1,y} - \frac{k_1}{L_1} \psi_{2,y} = \frac{k_1}{L_1} j \psi_{2,y} + \]

\[ + p \psi_{1,x} + p j \psi_{1,y} + j \omega_0 \psi_{1,y} + j j \omega_0 \psi_{1,y}; \]

\[ 0 = \frac{R_2}{L_2} \psi_{2,x} + \frac{R_2}{L_2} j \psi_{2,y} - k_1 \frac{R_1}{L_1} \psi_{1,x} = k_1 \frac{R_1}{L_1} j \psi_{1,x} + \]

\[ + p \psi_{2,x} + p j \psi_{2,y} + j s \omega_0 \psi_{2,y} + j j s \omega_0 \psi_{2,y}. \]

Now, let us represent the system of differential equations by complex inductive and capacitive resistance values:

\[ U_{22,x} = R_{i1} I_{02,x} + R_{i2} I_{02,y} + Z_{i1} \frac{\alpha_0}{\omega_0} pI_{02,x} + Z_{i2} \frac{\alpha_0}{\omega_0} pI_{02,y} + \]

\[ + j Z_{i1} I_{02,y} - Z_{i2} I_{02,y} + U_{c1,x} + j U_{c1,y}; \]

\[ I_{02,x} + j I_{02,y} = \frac{\alpha_0}{X_{i1}} \psi_{1,x} + \frac{\alpha_0}{X_{i1}} j \psi_{1,y} - \frac{\alpha_0}{X_{i1}} k_2 \psi_{2,x} - \frac{\alpha_0}{X_{i1}} j \psi_{2,y} + \]

\[ + \frac{\alpha_0}{Z_{c1} \alpha_0} pU_{c1,x} + \frac{\alpha_0}{Z_{c1} \alpha_0} pI_{c1,y} + j \frac{1}{Z_{c1}} U_{c1,x} - \frac{1}{Z_{c1}} U_{c1,y}; \]

\[ U_{c1,x} + j U_{c1,y} = \frac{\alpha_0 R_1}{X_{i1}} \psi_{1,x} + \frac{\alpha_0 R_1}{X_{i1}} j \psi_{1,y} - \frac{\alpha_0 R_2}{X_{i1}} \psi_{2,x} = \]

\[ - k_2 \frac{\alpha_0 R_1}{X_{i1}} j \psi_{2,y} + p \psi_{1,x} + j p \psi_{1,y} + j s \omega_0 \psi_{1,y} - j j \omega_0 \psi_{1,y}; \]

\[ 0 = \frac{\alpha_0 R_2}{X_{i1}} \psi_{2,x} + \frac{\alpha_0 R_2}{X_{i1}} j \psi_{2,y} - k_1 \frac{\alpha_0 R_1}{X_{i1}} \psi_{1,x} = k_1 \frac{\alpha_0 R_1}{X_{i1}} j \psi_{1,x} + \]

\[ + p \psi_{2,x} + j p \psi_{2,y} + j s \omega_0 \psi_{2,y} + j j s \omega_0 \psi_{2,y}. \]

For simplicity, the sign of the imaginary component in the system of equations can be omitted:

\[ U_{22,x} = R_{i1} I_{02,x} + Z_{i1} \frac{\alpha_0}{\omega_0} pI_{02,x} - Z_{i2} I_{02,y} + U_{c1,x}; \]

\[ 0 = R_{i2} I_{02,y} + Z_{i2} \frac{\alpha_0}{\omega_0} pI_{02,y} + Z_{i1} I_{02,x} + U_{c1,y}; \]
\[ I_{0.2,x} = \frac{\omega_0}{X_l} \psi_{1,x} - \frac{\omega_0 k_2}{X_l} \psi_{2,x} + \frac{1}{\omega_0 Z_{c_1}} pU_{c_{1,x}} - \frac{1}{Z_{c_1}} U_{c_{1,y}}; \]  
\[ I_{0.2,y} = \frac{\omega_0}{X_l} \psi_{1,y} - \frac{\omega_0 k_2}{X_l} \psi_{2,y} + \frac{1}{\omega_0 Z_{c_1}} pU_{c_{1,y}} + \frac{1}{Z_{c_1}} U_{c_{1,x}}; \]  
\[ U_{c_{1,x}} = \frac{\omega_0 R_1}{X_l} \psi_{1,x} - k_2 \frac{\omega_0 R_1}{X_l} \psi_{2,x} + p\psi_{1,x} - \omega_0 \psi_1; \]  
\[ U_{c_{1,y}} = \frac{\omega_0 R_1}{X_l} \psi_{1,y} - k_2 \frac{\omega_0 R_1}{X_l} \psi_{2,y} + p\psi_{1,y} + \omega_0 \psi_1; \]  
\[ \theta = \frac{\omega_0 R_2}{X_l} \psi_{2,x} - k_1 \frac{\omega_0 R_1}{X_l} \psi_{1,x} + p\psi_{2,x} - s\omega_0 \psi_2, \]  
\[ \theta = \frac{\omega_0 R_2}{X_l} \psi_{2,y} - k_1 \frac{\omega_0 R_1}{X_l} \psi_{1,y} + p\psi_{2,y} + s\omega_0 \psi_2. \]  

Let us express the derived parameters of the equivalent circuit and divide them by coefficients:

\[ pI_{0.2,x} = \frac{\omega_0}{Z_{c_1}} (U_{2.2,x} - R_1 I_{0.2,x} + Z_{c_1} I_{0.2,y} - U_{c_{1,x}}); \]  
\[ pI_{0.2,y} = \frac{\omega_0}{Z_{c_1}} (-R_1 I_{0.2,y} - Z_{c_1} I_{0.2,x} - U_{c_{1,y}}); \]  
\[ pU_{c_{1,x}} = (I_{0.2,x} - \frac{\omega_0}{X_l} \psi_{1,x} + \frac{\omega_0 k_2}{X_l} \psi_{2,x} + \frac{1}{Z_{c_1}} U_{c_{1,y}}); \]  
\[ pU_{c_{1,y}} = \omega_0 Z_{c_1} (I_{0.2,y} - \frac{\omega_0}{X_l} \psi_{1,y} + \frac{\omega_0 k_2}{X_l} \psi_{2,y} - \frac{1}{Z_{c_1}} U_{c_{1,x}}); \]  
\[ p\psi_{1,x} = U_{c_{1,x}} - \frac{\omega_0 R_1}{X_{l_1}} \psi_{1,x} + k_2 \frac{\omega_0 R_1}{X_l} \psi_{2,x} + \omega_0 \psi_1; \]  
\[ p\psi_{1,y} = U_{c_{1,y}} - \frac{\omega_0 R_1}{X_{l_1}} \psi_{1,y} + k_2 \frac{\omega_0 R_1}{X_l} \psi_{2,y} - \omega_0 \psi_1; \]  
\[ p\psi_{2,x} = -\frac{\omega_0 R_2}{X_{l_2}} \psi_{2,x} + k_1 \frac{\omega_0 R_2}{X_{l_2}} \psi_{1,x} + s\omega_0 \psi_2; \]  
\[ p\psi_{2,y} = -\frac{\omega_0 R_2}{X_{l_2}} \psi_{2,y} - k_1 \frac{\omega_0 R_2}{X_{l_2}} \psi_{1,y} + s\omega_0 \psi_2. \]  

The resulting system of equations (45-52) can be supplemented with the motion equation:

\[ ps = \frac{1}{T_m} m_c - \frac{k_1}{T_m X^2} (\psi_{1,x} \psi_{2,y} - \psi_{1,y} \psi_{2,x}), \]  

(53)
where \( s \) is slip; \( T_m \) – rotational inertia constant; \( K_1 \) – stator coupling coefficient; \( X'_2 \) – transient inductive resistance of the rotor winding; \( m_c \) – resistance torque in the slip function.

The input voltage is expressed using the function [3]:

\[
U(t) = \left( t - k \right) \cdot \left( t - t_1 \right) + k \cdot \left( t - t_2 \right),
\]

where \( t_1 \) – the moment when the voltage begins to decrease; \( t_2 \) - the moment when the voltage is restored; \( k \) – the voltage reduction degree coefficient.

Let us represent the resulting system of equations in the per unit format (53-52). Then we supplement this system of equations with the motion equation (53) and the stress function (54).

The basic values are taken as:

\[
S_n = \sqrt{3} \cdot U_{nom} \cdot I_{nom} = \frac{3}{2} \cdot \frac{U_b \cdot I_b \cdot p}{\omega_b} = 8238.8,
\]

where \( \omega_b = \Omega_b = 2 \cdot \pi \cdot f / p = \omega_0 / p \cdot \) (\( \omega_0 = \Omega_0 = 2 \cdot \pi \cdot n_{nom} / 60 = 101.3 \)) \( \) rad/s – rotational speed,

\[
U_b = \frac{\sqrt{2} \cdot U_{nom}}{\sqrt{3}} = 4899; \quad I_b = \sqrt{2} \cdot I_{nom} = 117.35; \quad Z_b = \frac{U_b}{I_b} = 41.73;
\]

\[
\Psi_b = \frac{U_b}{\omega_b}; \quad \Delta M_{dep} = \frac{\Delta M_{dep}}{M_b};
\]

\[
T_m = \frac{J \cdot \omega_m^2}{M_{nom}}; \quad T_{mb} = \frac{J}{4M_b}; \quad T_{mb} = \frac{T_m}{T_{mb}},
\]

where \( J = J_d + J_p \) is the total inertia moment of the mud pump unit.

4. Experimental results
The modeling has provided the following results: electromechanical, electromagnetic and resistance torques, as well as start-up current, voltage, true and reactive power.

![Graphs of current and input voltage dependence with the mud pump individual compensation unit enabled at input voltage decreased to 0.95 p.u. and under 20% voltage dip during 2.75 seconds](image)

**Figure 4.** Graphs of current and input voltage dependence with the mud pump individual compensation unit enabled at input voltage decreased to 0.95 p.u. and under 20% voltage dip during 2.75 seconds

5. Discussion
The simulation results have shown that, in case of all possible disturbances of power distribution network dependent and independent variables, i.e. changes in the input voltage level and drop in the mains voltage level and changes in the resistance torque by 20% due to the drilling mud viscosity, the mud pump electric drive start is completed successfully.
Figure 5. Graphs of electromagnetic torque, compensation device terminals voltage and input voltage dependence with the mud pump individual compensation unit enabled at input voltage decreased to 0.95 p.u. and under 20% voltage dip during 2.75 seconds.

Figure 6. Graphs of electromechanical torque dependence with the mud pump individual compensation unit enabled at input voltage decreased to 0.95 p.u. and under 20% voltage dip during 2.75 seconds.

Figure 7. Graphs of slip, rotor rotation frequency and input voltage dependence with the mud pump individual compensation unit enabled at input voltage decreased to 0.95 p.u. and under 20% voltage dip during 2.75 seconds.

6. Summary and conclusions
The introduction of a bypass is reasonable in order to improve the operation process reliability and continuity. It is also recommended to use an individual compensation unit to reduce losses in the power supply system. The results of mathematical modeling of the mud pump electric drive operating
modes in the proposed power supply configuration prove guaranteed start taking into account all possible disturbances of power distribution network dependent and independent variables.

References
[1] Shvetskova L V 2016 Improving the energy efficiency of the production well electrical complex with high viscosity oil thesis of Ph.D. in Engineering Science 05.09.03, Samara
[2] Nurbosynov D N, Tabachnikova T V and Shvetskova L V 2015 Optimising the electromagnetic torque of the production well electric drive start and self-start in case of viscous and high-viscosity oil recovery Monthly production and engineering magazine Industrial Energy 10 25–29
[3] Nurbosynov D N 1999 Methods of calculation and mathematical modeling of voltage and power consumption in steady-state and transient processes: Monograph (SPb.: Energoatomizdat)
[4] Konovalov Y V 2012 Mathematical modeling of the AC motor start process (Bulletin of Saratov State Technical University) 1 (68) 146–149
[5] Kozyaruk A E, Belov M P and Zementov O I 2006 Electric drive and automation system engineering: a study guide for higher educational institution students (Moscow: Publishing house ACADEMIYA)