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Prospects for Application of Multiphase Asynchronous Drives in the Field of Drilling Rigs

Andrey V. Brazhnikov[1], Vasilii I. Panteleev[2], Nikolay N. Dovzhenko[3], Vasudevan Saravanan[4], Dalerdzhon A. Sharipov[3]
[1]*(Department of Electrical Engineering, Polytechnic College/ Siberian Federal University, Russia)*
[2]*(Department of Electrotechnical Complexes, Polytechnic College/ Siberian Federal University, Russia)*
[3]*(Department of Drilling, College of Petroleum and Natural Gas/ Siberian Federal University, Russia)*
[4]*(Department of Electrical and Electronics Engineering, Arunai Engineering College/ Anna University, India)*
Corresponding Author: Andrey V. Brazhnikov

ABSTRACT: *The electrical drive system of a number of drilling rigs must yield a sufficiently wide range of the smooth regulation of motor speed (for example, rotary drives, travel drives). The use the multiphase (i. e. with the number of the phases being equal to five or more) frequency controlled electric drives with induction motors in these systems allows to improve considerably their technical-and-economic characteristics (for example, manufacturing cost, reliability etc.) in comparison with the case when 3-phase induction motors or DC motors are used there. The phase number being increased and some non-traditional control methods being used, the mass-and-overall dimensions of the induction motor drives approach that of the same power hydraulic drives.*

Keywords: *Drilling rigs, multiphase asynchronous drives, manufacturing cost, mass-and-overall dimensions, reliability.*

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I. INTRODUCTION

The electric drive systems of a number of drilling rigs must yield a sufficiently wide range of the smooth regulation of motor speed (for example, rotary drives, travel drives). Their construction is often based on the use of DC motors that have a number of drawbacks. These drawbacks are now universally known (for example, deficient reliability). The electric drives, the construction of which is based on the induction motors having a stepwise regulation of speed of rotation, are the alternative for such drives. They have greater reliability and more inexpensive. But they do not yield the smooth regulation of motor speed.

The use of the electric drives, the constructions of which are based on the frequency-controlled 3-phase induction motors, is more expedient for the field of drilling rigs. They are able to yield a wide range of smooth regulation of the speed.

Further improvement of the characteristics of the electromechanical systems of drilling rigs is achieved by increasing the phase number (i.e. the number of the phases) of these electric drives more than four [1]-[3]. Characteristics and properties of such multiphase (i.e. with $m \geq 5$, where m is phase number) electromechanical systems are presented hereafter in this paper.

II. STRUCTURE OF MULTIPHASE INDUCTION MOTOR DRIVE SYSTEM

The structure of the multiphase inverter drive, in which the power supply of an induction motor is realized by an inverter, is the same as that of the analogous 3-phase system (Fig. 1).

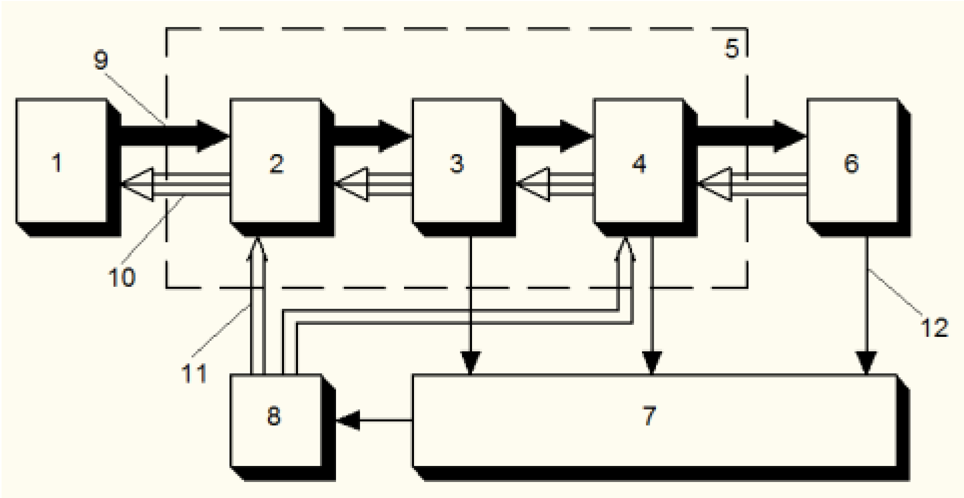


Figure 1: The structure of the multiphase inverter drive: 1 – AC supply; 2 – rectifier circuit and device for regeneration of energy; 3 – filter; 4 – *m*-phase inverter; 5 – frequency converter; 6 – *m*-phase induction motor; 7 – sensor system (sensor of currents, torque or slip, etc.); 8 – drive control system; 9 – channel of energy consumption; 10 – channel of energy regeneration; 11 – signals of control; 12 – feedback signals.

The construction of multiphase inverters is analogous to that of 3-phase ones. Both thyristors and transistors may be used in these devices. The simplified circuit of *m*-phase transistor inverter, that inverters voltage, is presented in Fig. 2.

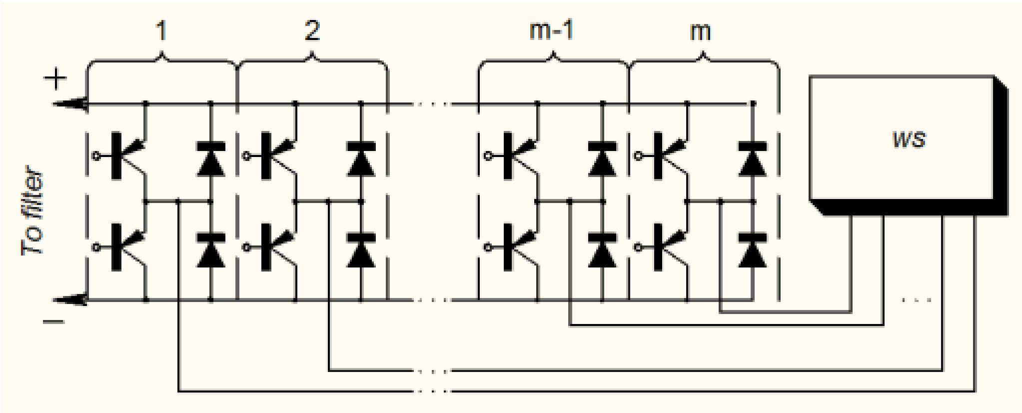


Figure 2: The simplified circuit of multiphase transistor inverter: *WS* – stator winding set of multiphase induction motor.

The making of the stator winding set of a multiphase induction motor is the same as that of the winding set of a 3-phase motor. But the multiphase system of the stator windings consists of the greater number of the phase coils (more than four). In the simplest case these coils (i.e. phase windings) are located relative to each other at the following space angle:

$$\alpha = 2\pi / (p \cdot m), \tag{1}$$

where p is a pole number (i.e. number of the poles) of the induction motor. The phase number being more that four, the phase windings form absolutely symmetrical winding system in this case as well as it is when m = 3.

The manufacture of multiphase induction motor, inverters and complete electric drive systems is not associated with any qualitative change in the technology of the manufacture of analogous 3-phase apparatuses. The technology change, that is necessary to transfer from making 3-phase motors to making multiphase ones, is not more difficult than the transfer to the manufacture of the induction motors having the same phase number and other pole number. And the transfer from making the 3-phase inverters to making the multiphase ones does not need any technology change at all, because only more number of the less powerful (i.e. lower price) semiconductor devices (transistors, thyristors, diodes) and other electric circuit elements are needed for this transfer.

III. TRADITIONAL CONTROL OF MULTIPHASE ASYNCHRONOUS DRIVES

Increase of a phase number allows to improve a number of characteristics of frequency-controlled induction motor drives even if the mode of control of a multiphase inverter is traditional, i.e. if this mode is the same as that which is used in the field of 3-phase induction motor drive systems [1].

In this case the increase of a phase number of an induction motor drive leads to the following (without any change in the algorithm of inverter control when only a phase number increases):

– opportunity for decrease of the mass-and-overall dimensions and manufacturing cost of the filter in the input circuit of inverter (about 2.0-2.5 times decrease of these mass-and-overall dimensions when m increases from 3 to 9);

– opportunity for decrease of the electrical losses in a rotor circuit of an induction motor (by about 30 % when a phase number increases from 3 to 9);

– opportunity for expansion of the speed regulation range of an induction motor down from the nominal speed value without appearance of the step effect (about 3-7 times expansion when phase number increases from 3 to 9).

Besides, increase of a phase number is to expand the power range of AC inverter drives (including transistor inverter drives) in the direction of increase of their powers because the powers of semiconductor devices (thyristors, transistors, diodes), that are needed for making multiphase inverters, decrease when a phase number increases (but the number of these devices increases too) and any parallel connection of these less power devices is not needed [4]-[8].

IV. NON-TRADITIONAL CONTROL OF MULTIPHASE ASYNCHRONOUS DRIVES

The increase (more than four) of a phase number of inverter drives gives opportunity for the use of some non-traditional methods of induction motor control [1]-[3], [8]-[21]. The use of these methods together with traditional ones allows to expand the control resources of inverter drives. The proportional-angle method is one of these non-traditional control methods. It may be used only if a phase number is more than four. The use of the proportional-angle method allows to regulate parameters of the mechanical characteristics of multiphase induction motors (in particular, to regulate synchronous speed of rotation) without any change in frequency and value of stator voltage.

The transition from any routine control method to the proportional-angle one consists in the H times change in the electrical angle between voltages (or currents) of the nearest phases of an inverter.

The use of this non-traditional control method is most effective when a phase number of a drive system is equal to the following:

$$m = A_m \cdot H \ , \tag{2}$$

where A_m is some whole number; $A_m \geq 3$. In this case there is the effect adequate to the synchronous change in a phase number and in a pole number of a motor (but in this case the real number of the motor poles is not changed). The synchronous speed of rotation of the motor rotor is inversely proportional to the value H and the maximal torque of the motor is directly proportional to this value. The set of mechanical characteristics of the 30 kW power 16-phase induction motor for the different values of the parameter H is presented in Fig. 3 as an example, where the symbols represent: ω is speed of rotation; M is torque of the motor.

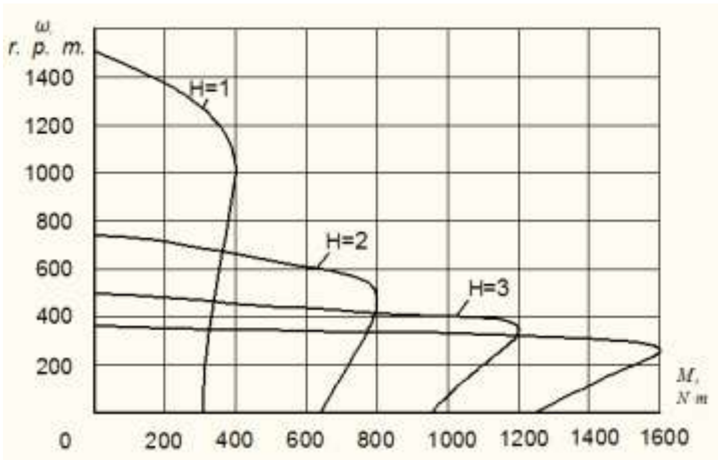


Figure 3: The mechanical characteristics of 30 kW power 16-phase induction motor.

If a phase number does not satisfy equation (2), effectiveness of this control method decreases, but even in this case the behaviour of an mechanical characteristic of a motor is analogous. The set of mechanical characteristics of the 30 *kW* power 5-phase induction motor is presented in Fig. 4 for the case when the routine 180-degree (line 1) and the proportional-angle (line 2) control methods are used and the frequency of stator voltage is invariable, where $W = \omega / W_0$; W_0 is frequency of inverter voltage.

The use of the proportional-angle control method allows either to increase torque of a multiphase induction motor without any increase of this machine power or to decrease its power (and so its cost and mass-and-overall dimensions) without any increase of motor losses that are caused by the saturation of the motor magnetic circuit.

The degree of decrease of the motor nominal power depends on the value of the ratio $K_m = M_s / M_n$, where the symbols represent the following: M_n is nominal torque of the motor; M_s is motor torque that must be achieved in the field of the low speeds of rotation (for example, stop torque). The dependence of the decrease degree of the motor nominal power on the value of the coefficient K_m is presented in Fig. 5, where $K_p = P_r / P_{pa}$; P_r is power of traditional controlled motor; P_{pa} is power of motor when the proportional-angle control method is used.

There are minimum values (m_m) of a phase number of a drive system that yield the achievement of such decrease of value K_p for every concrete value K_m. The dependence of m_m on K_m is shown in Fig. 5.

Besides, the use of the proportional-angle method allows to continue controlling the motor even if an abnormal situation arises (for example, a phase wire broke). In this case the use of this control method allows to increase the time of uninterrupted operation of the drive system by about 30-50 % and even more.

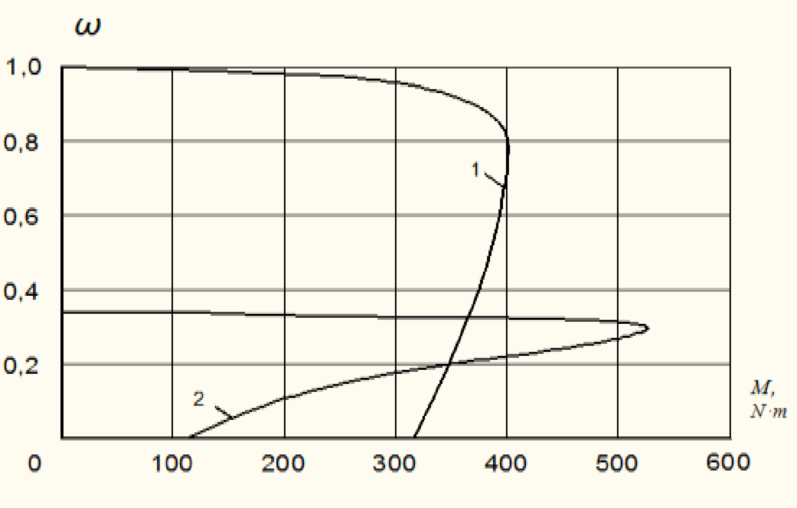


Figure 4: The mechanical characteristics of 30 kW power 5-phase induction motor.

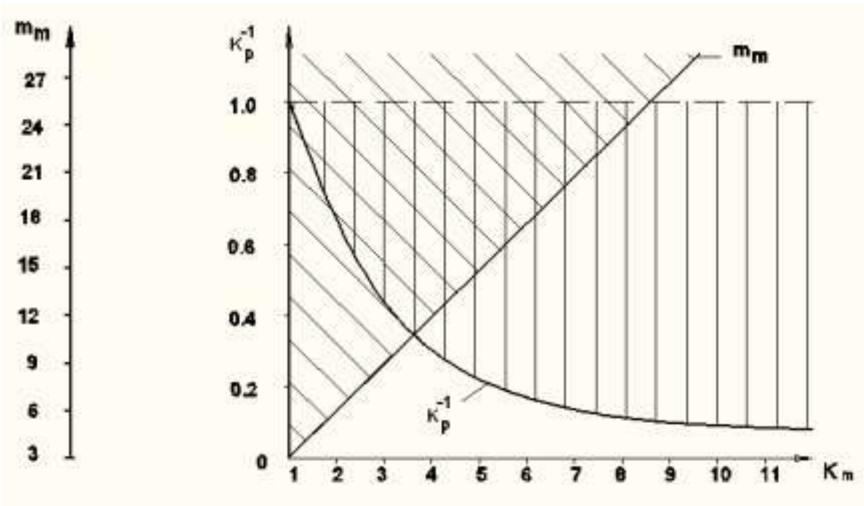


Figure 5: The K_m – dependences of m_m and K_p^{-1}.

Some other non-traditional algorithms of multiphase inverter control exist. When these algorithms are used, the change of the torque oscillation amplitude of a multiphase motor over a wide range becomes possible. Two variants of torque oscillations that can be obtained using these algorithms for $m = 9$ are shown in Fig. 6, where the symbols represent: M_0 is constant component of torque; M_v is torque oscillations; t is time. The increase of the amplitude of the torque oscillations (when these control algorithms are used) can allow to increase the effectiveness of destruction of rock without any increase of drive power (as well as it is done in hydraulic giants that produce the pulsating water jet).

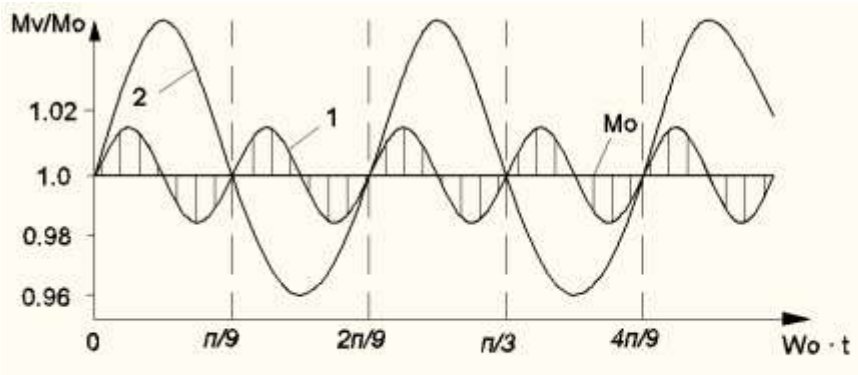


Figure 6: The torque oscillations of 9-phase induction motor: 1 – routine 180-degree control algorithm; 2 – non- traditional algorithm of inverter control.

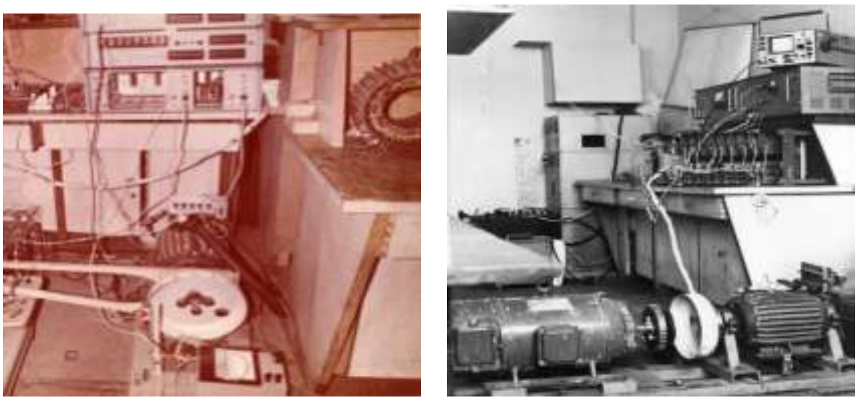
V. EXPERIMENTAL RESULTS

Experiments have been carried out on 6- and 9-phase systems “inverter – induction motor”. Exterior views of experimental 9-phase inverter-fed induction motor drive system are shown in Fig. 7 as an example. Obtained oscillograms of currents and voltages of the motor and inverter and motor speed and torque are shown in Fig. 8, where u_y is voltage of control by inverter transistors; u_u is voltage in the input circuit of inverter; i_u is current in the input circuit of inverter; u_s is motor (and inverter) phase voltage; i_u is motor (and inverter) phase current; M is motor torque; n is motor speed of rotation.

Results of theoretical modeling are shown by points on above mentioned oscillograms. As can be seen from the oscillograms, difference between theoretical and experimental results is slight. By this means results of experimental researches confirm correctness of theoretical conclusions.

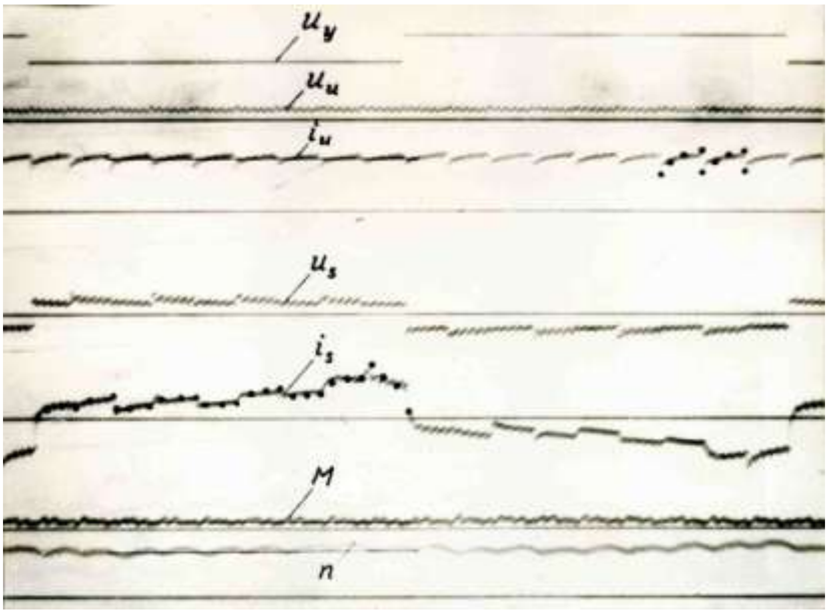
VI. CONCLUSION

The use of multiphase frequency controlled induction motor drives is one of the most effective methods of improvement of the technical-and-economic characteristics of drilling rigs including their manufacturing cost, reliability, effectiveness of rock destruction, mass-and-overall dimensions. The manufacture of multiphase drives is not more difficult than that of 3-phase analogous apparatuses. The mass-and-overall dimensions of the multiphase induction motor drives, in which the proportional-angle control method is used, approach that of hydraulic drives and can even be less than they.

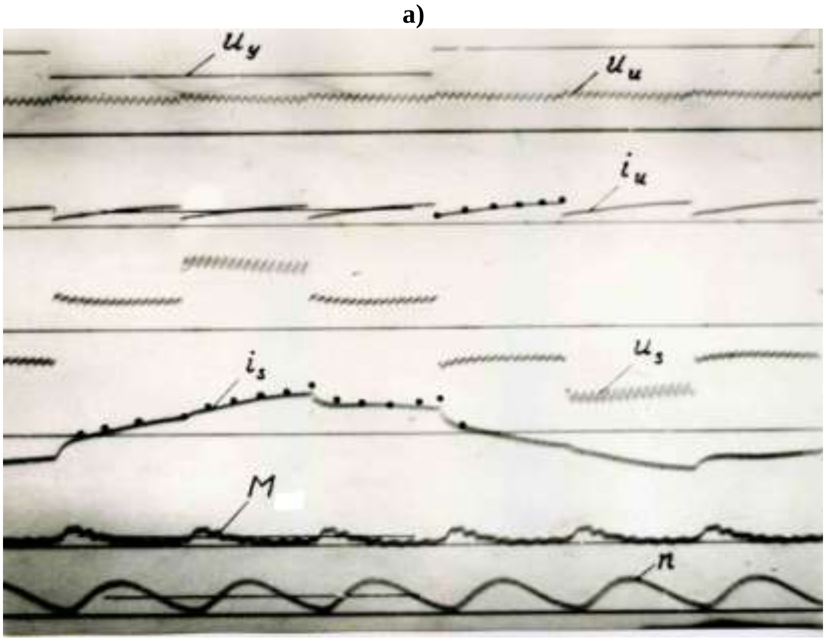


a) **b)**

Figure 7: Experimental 9-phase inverter-fed induction motor drive system: a) – determination of motor mechanical characteristic, currents and voltages in motor and inverter; b) – determination of motor starting torque.



a)



b)

Figure 8: Obtained oscillograms of currents, voltages, speed and torque of the 9-phase system “inverter – induction motor”: a) – *H* = 1; b) – H = 3.

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