Research of frequency converters energy characteristics of drilling rigs

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Abstract. The investigation deals with multi-motor electric drives with frequency converters of various structures: with a common converter, with an individual converter, with a multi-inverter frequency converter. Their shortcomings and advantages were analyzed and there were drawn conclusions about the expediency of using each structure. Expediency of using multi-inverter frequency converters with an active frond end was shown to ensure the highest power characteristics of multi-motor electric drives of drilling rigs' main mechanisms.

1. Introduction

Mineral resource industry is one of the most important and fastest-growing industries of the Russian Federation, however a vast number of the country's production fields are located in areas with complex operating and development conditions. In most cases such regions are located far away from power lines; so the drilling rigs (Fig.1) developing wells in the specified conditions are required to be self-contained and energy-efficient.

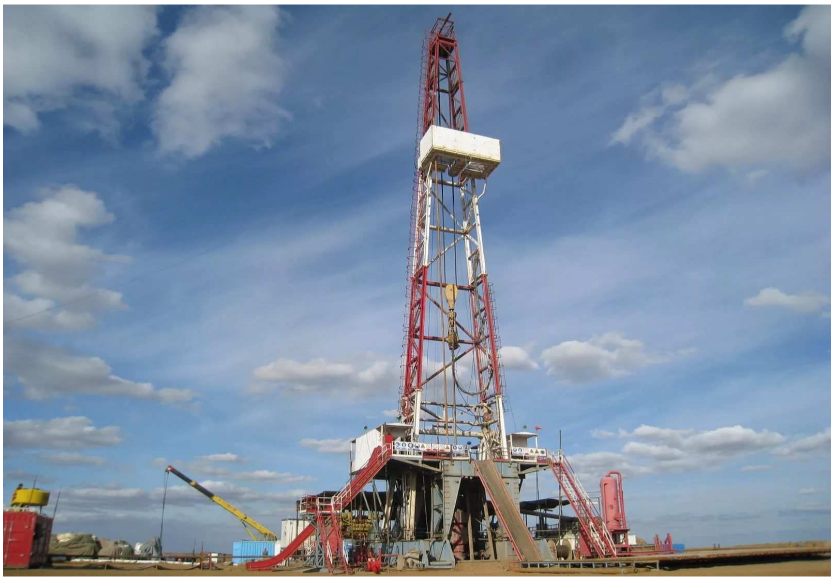

Figure 1. Drilling rig

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The modern electric drive of drilling rigs is a multi-motor electro-mechanical system that must be regulated. Special features of such electric drives are a high power-to-weight ratio, provision of main technological operations, a high degree of automation, high reliability requirements, a high potential for energy saving, high requirements for mass dimensions [1-3].

2. Materials and methods

The basis of a multi-motor electric drive of the main mechanisms of drilling rigs are non-contact electric motors, usually asynchronous motor. Widespread use of asynchronous motors was due to simple design, high reliability, low cost and the ability to provide speed control in transient and steady-state modes with simple technical means. When developing the multi-motor drives, a development group had been set a crucial task to choose the frequency converter (FC) structure. A possibility of high level energy efficiency provision and electromechanical system compatibility and reliability depends exactly on this task solution.

Let us consider various ways to build the FC's structure of a multi-motor electric drive, their disadvantages and advantages. Most companies-manufacturers of drive technology build the electric drive by a two-link scheme. The composition of such a frequency converter includes: a diode rectifier and an inverter. Let us consider the possibility of controlling a group of induction motors of a drilling rig using a common frequency converter, the structural diagram of such electric drive is shown in Fig. 2.

The electric drive with a common frequency converter has the following disadvantages: it is impossible to perform individual motor control, low power factor, a high negative effect on the quality of the electric power, inefficient use of braking power (recovery as heat over deceleration device).

In addition, its use is possible only in technological complexes, the executive mechanisms of which operate simultaneously and in identical modes, and the operating conditions of the drilling rig are characterized by a large uneven load caused by a change in the properties of the face, the nature of the fracture process, the occurrence of significant vibrations during machine operation.

Thus, the use of an electric drive with a common frequency converter for power supply and control of the main mechanisms of the drilling rig is inexpedient and inefficient.

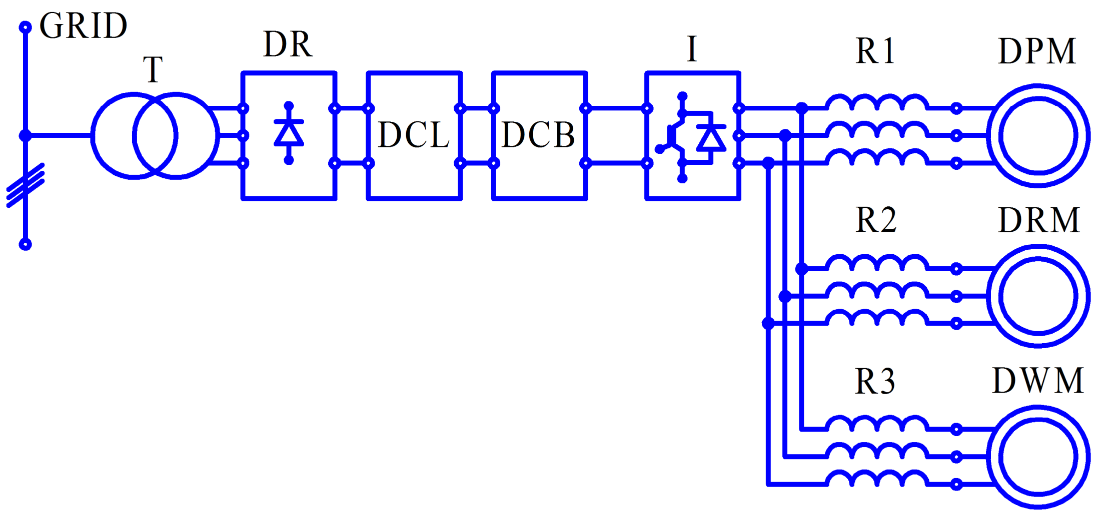

Figure 2. Block diagram of multi-motor ED with common FC: T – transformer, DR – diode rectifier, DCL – DC-line, DCB – DC-brake, I –inverter, R – reactor, DPM – drilling pump motor, DRM – drilling rotor motor, DWM – draw work motor

In conditions when the operation of the actuators is characterized by uneven load and occurs in different modes, as in the case of a drilling rig, individual frequency converters can be used (Fig. 3). The main advantage of an electric drive with individual frequency converters is the possibility of independent separate control of the electric drive motors. However, such electric drive is characterized by a low level of electromagnetic compatibility and a power factor; besides, large dimensions and high costs are significant drawbacks of this structural solution. Also the modernization process of such electric drive, the implementation of energy-saving measures and other measures to improve its efficiency become significantly complicated.

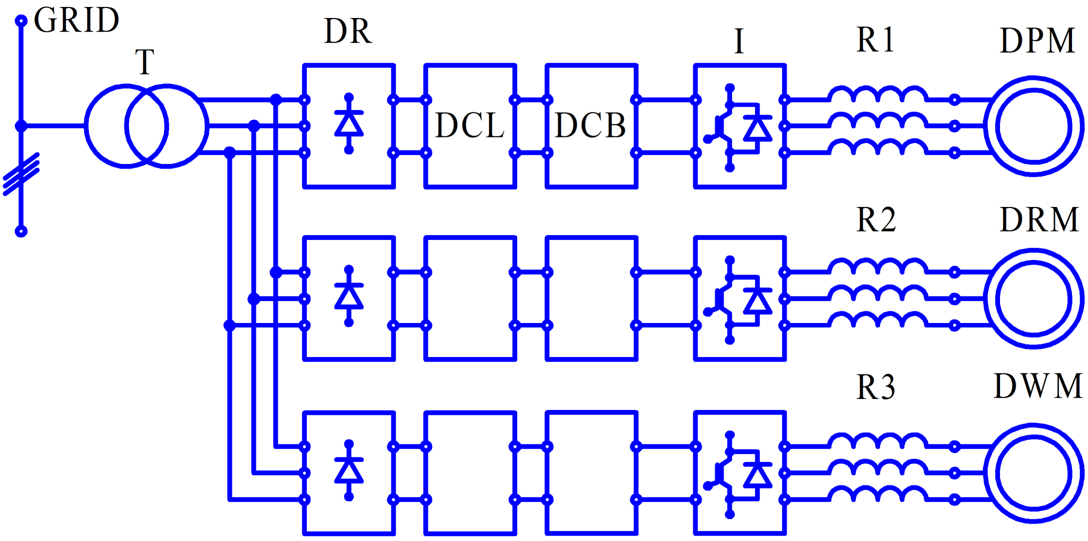

Figure 3. Block diagram of multi-motor ED with individual FC

Formation of a group electric drive in which individual frequency converters are used, as a rule, occurs with the consequent modernization of obsolete electric drives of drilling rigs with the introduction of converters. In many cases this happens without taking into account their electromagnetic compatibility, the influence of the frequency converter on the quality of electricity in the enterprise grid and other factors of their effective use [4-5].

In the complex solution of the control and energy efficiency problems of the electric drive, a multi-inverter frequency converter can be used (Fig. 4). Such frequency converter has a number of advantages, namely: the possibility of individual motor control, fewer semiconductor modules, the use of a common DC bus, the use of a common braking device, the ease of mounting at a drilling site, improved weight and size characteristics, reduced losses and power consumption.

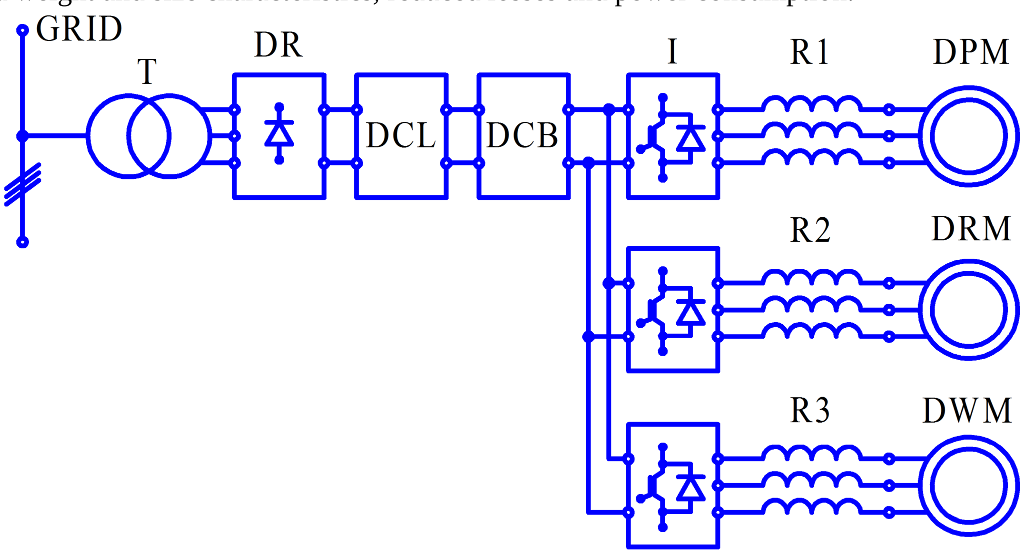

Figure 4. Block diagram of multi-motor ED with multi-inverter FC and DR

Despite the numerous advantages of using a multi-inverter frequency converter, it has a number of drawbacks due to the use in its structure of a diode rectifier, which, as a rule, is installed at the input of such frequency converter. These disadvantages include: low power factor of the electric drive, high distortion of voltage and current consumed by the electric drive, lack of the possibility of electricity recuperation, excessive power consumption. The widespread use of a diode rectifier in the structure of a multi-inverter frequency converter is due to its low cost.

To eliminate the aforementioned shortcomings and complex solutions to the problems of energy efficiency of the drilling rig, it is advisable to use an active rectifier on fully controlled thyristors (transistors) in the structure of a multi-inverter frequency converter. The structural diagram of such superconductor is shown in Fig. 5.

When using an active rectifier, a high level of electromagnetic compatibility of the electric drive with the grid and other loads is provided. Also, the benefits of this solution include: power factor at the unit level, regeneration of brake energy, autonomization in case of power failure or a significant decrease in the voltage amplitude in the grid (by providing an energy isolation of the grid and electric drive motors) [6-8].

It is necessary to point out that the use of an active rectifier allows the input transformer to be replaced by grid reactors if the voltage levels of the grid and motors match. At the same time, the increase in mass-dimensional characteristics is achieved by eliminating the DC-brake device. In this case, the braking energy of the drive motors is recovered in the grid. Thus, the mass-dimensional characteristics of a multi-inverter frequency converter using an active rectifier in its structure is higher than using a diode rectifier.

It should be noted that the power of the active rectifier of the frequency converter must correspond to the power of all connected motors. The cost of the active rectifier is much larger than the cost of the diode, however, the high cost of the active rectifier during the implementation phase is compensated by replacing the diode rectifiers of each inverter by one common (active rectifier), excluding the transformer and the braking device. In the period of operation, the main economic effect is achieved by providing a single power factor and a high quality of electric power in the grid [9-10].

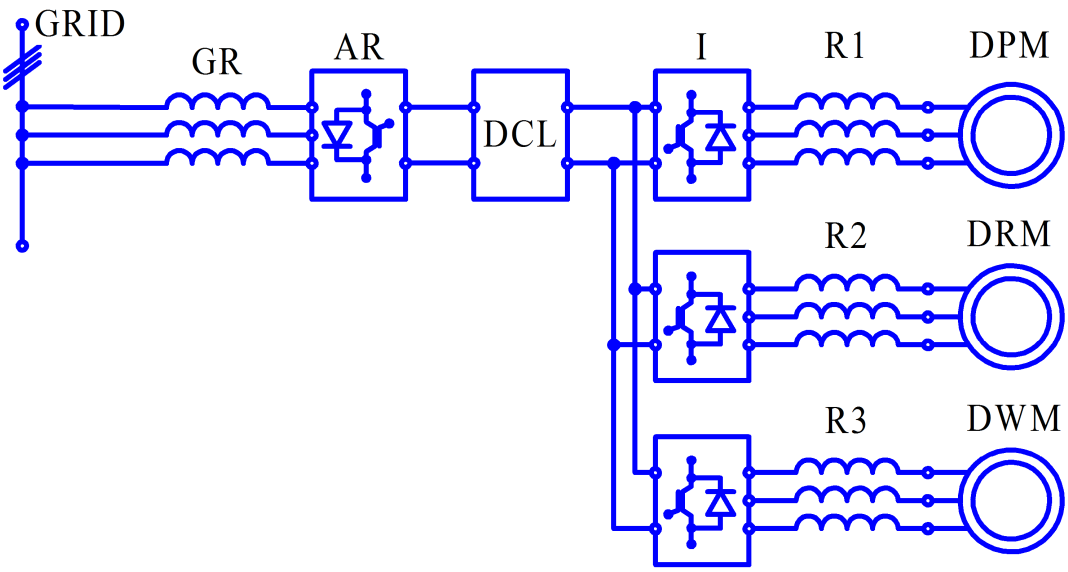

Figure 5. Block diagram of multimotor ED with multi-inverter FC and AR: GR – grid reactor, AR – active rectifier.

3. Results and Discussion

A study of the efficiency of the introduction of an active rectifier in the power section of the frequency converter and its effect on the quality of electrical energy in the electric power system of the drilling rig was carried out by simulation modeling in the Simulink MatLab environment. The investigation results are represented by oscillograph traces of input and output currents and voltages, given in Figures 6 and 7.

Presented in Fig. 6 oscillograms show: voltage and current at the input of the active rectifier coincide in shape and phase and have a sinusoidal form - this ensures the operation of the grid elements in nominal modes and allows the drive to work with a power factor close to unity. As a result, the electric power equipment of the drill power supply grid is unloaded from the reactive power.

Fig. 7 illustrates the oscillogram showing the voltage change in the DC line when the load is connected. It shows that the active rectifier ensures the constancy of the voltage, with a slight voltage drop in the draft load. Thus, the use of active rectifier ensures the operation of a multi-motor electric drive without negatively affecting the shape of the voltage of the power supply grid and the consumption of sinusoidal currents by the electric drive. This factor allows the electric drive to operate with almost a single power factor, thereby reducing the power consumption of the drilling rig.

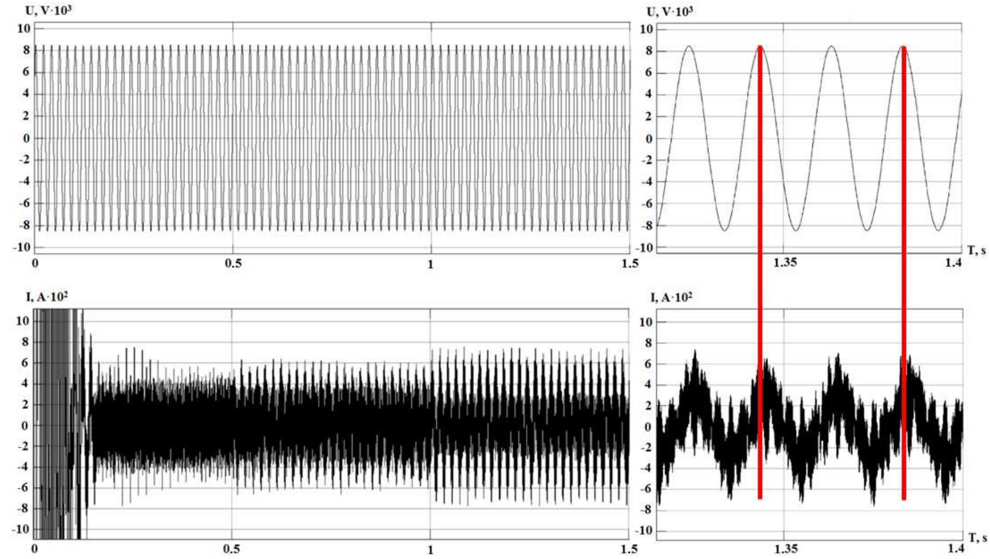

Figure 6. Change of voltage and current at active rectifier input when the load is added in constant voltage circuit

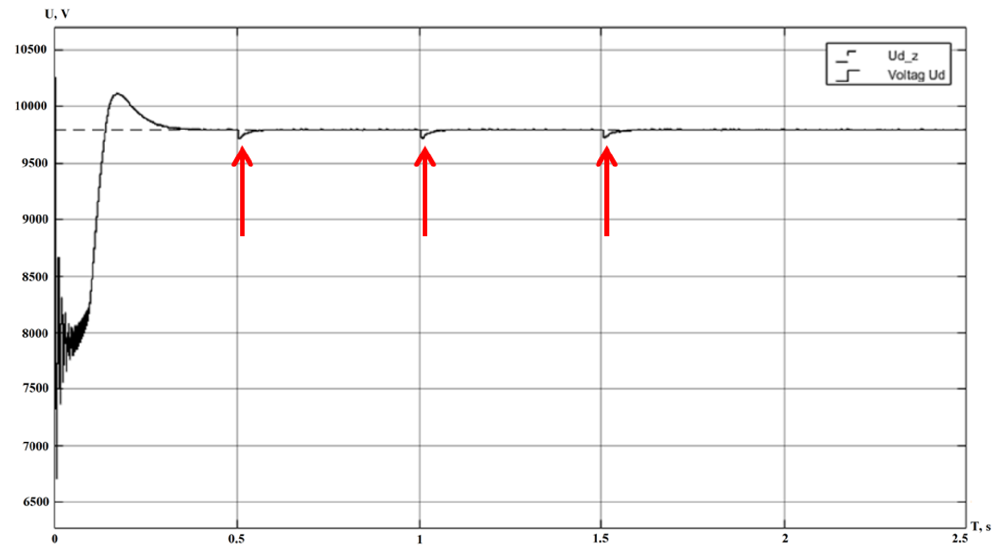

Figure 7. Change of voltage in the constant voltage link when load adding

4. Conclusion

It should be noted that the use of an active rectifier provides a high level of electromagnetic compatibility of the electric drive with the grid and load, resulting in an energy decoupling of the grid and motors. From this it follows that a multi-inverter frequency converter with an active rectifier can provide power consumption to drilling rig motors not only in steady-state, but also in transient modes for the purpose of forming specified technological operations and processes. All this suggests that the use of an active rectifier in the structure of the multi-inverter frequency converter of the electric drive of the main mechanisms of the drilling rig greatly increases its energy efficiency and technical capabilities. Thus, this structure of the electric drive fully meets modern requirements and provides high economic efficiency.

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