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PROVIDING ENERGY DECOUPLING OF ELECTRIC DRIVE AND ELECTRIC GRIDS FOR INDUSTRIAL ELECTRICAL INSTALLATIONS

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Subjects of the research are industrial electric drives, witch maintain the operation of main actuating units of production machines and installations during the development of mineral resource deposits.

The goal is to research the possibility to ensure the energy decoupling of industrial electric drives and electric grid by means of structural implementation of active rectifiers into frequency converters. The main purpose of energy decoupling is to eliminate the negative impact of low quality electric energy and changes in energy parameters on electric drive operation.

In order to accomplish energy decoupling of electric drive with active rectifier, methods of mathematical and simulation modeling with mathematical application software package were used. The integrated simulation model with two electric drives, including active rectifier (energy decoupled electric drive) and diode rectifier (standard type electric drive), were created. Simulation model is provided with tools for oscillographic testing and analysis of the impact of power quality parameters on frequency converters and drive motors operation.

The analysis of effectiveness of energy decoupling by means of active rectifier of frequency converter shows that drive motor completely retains the stability and controllability of rotation frequency and torque during the changes of power quality parameters in electric grid. The use of active rectifier allows to ensure the operation of electric drive in required mode in case of voltage decrease by 30 % with normative value of 5-10 %, i.e. energy decoupling provides high stability margin for voltage. Electric drive with active rectifier ensures energy decoupling in case of asymmetry of supply voltage. The control of mechanical variables of induction motor during offsets in amplitude and frequency in all phases of electric grid is ensured to be on required level.

Key words: electric drive, electric grid, energy decoupling, energy compatibility

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Introduction. In order to ensure required operating mode of motors of industrial electric drives, frequency converters are used. Modern types of converters allow forming characteristics of drive machines in accordance with preset mechanical and energy parameters.

For the control of motors in modern industrial electric drives scalar, vector and direct torque control systems are used.

In order to control frequency converters of modern industrial electric drives, pulse-width modulation, space vector modulation and relay modulation are utilized.

Biggest part of research in the field of industrial electric drives is dedicated to development and examination of those systems and their effectiveness [4, 6, 9, 11, 14]. Another part of research is conducted in the field of development of convertor structure and electric drives as a whole, including the field of rational selection and validation of drive machine types and types of converters [1-3, 8, 13]. It is necessary to note big cluster of studies of energy efficiency of electric drives [4, 5, 7, 10, 12].

At the present time the distinctive feature of industrial electric drives, especially in mining, oil and gas industries, is operation in conditions of low quality of electric energy. In order to ensure required operating mode of industrial electric drives and to reduce the effect of low quality electric energy supplied from grid, methods of modification of electric energy supply systems are used, which is not always rational solution. The most effective instrument for solving this problem is the ensuring of energy decoupling of electric drive and electric power grid.

The establishing of energy decoupling of electric drive and electric grid must be viewed as a part of complex problem of securing the energy compatibility of electric drives [1]. Problem of energy compatibility includes following main questions: ensuring the energy decoupling of electric

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drive and the grid, control of braking power flows of drive motor, control of power flows, supplied to electric drives, and other questions.

In the present paper the results of research on effectiveness of providing energy decoupling of electric drive and electric power supply grid by means of implementation of active rectifier into driver converter structure.

Problem statement. The basis of modern technological tools for mineral resource deposits exploitation is electrical installations with high-technology electric drives, characterized by following features:

• electric drives of modern technological machines are the main type of driving units of the operating mechanisms;

• technical and operational characteristics of electric drives determine effectiveness and economic viability of mineral resource deposits;

• electric drives incorporate frequency converters, which provide necessary characteristics and operating modes of drive motors;

• electric drives are the main consumers of electric energy;

• electrical drives are built in accordance with one- or multi-motor schemes;

• electrical power supply of industrial electrical installations is conducted by grids with low quality electric energy, which causes significant negative impact on electric drive operation in electrical installations connected to those grids.

Several examples of electrical installations with electric drives, corresponding to those specifics, could be noted:

• drilling rigs for oil and gas deposits (electric drive of main machinery – hoisting winch, rotary table or top drive, drill pumps);

• mine excavators for open pit mining facilities for solid mineral resources (electric drive of main machinery – lift, thrust, rotation, motion);

• mining machines for underground mines for solid mineral resources (electric drive of main machinery – screw, thrust, conveyor).

Modern electric drives of industrial facilities (drilling rigs, mine excavators, mining machines, conveyer systems and others) are based upon contactless induction, synchronous and switched reluctance motors with frequency converter (FC). Structural diagram of electric drive with frequency converter is represented in Fig.1.

Fig.1 shows voltages in different parts of electric drive scheme. Voltage of the transformer secondary windings (input voltage of FC diode rectifier) is formed as

$$U_2 = \frac{U_1}{K_{tr}}, \tag{1}$$

where U_1 – electric grid voltage (primary winding of transformer); K_{tr} – transformation ratio.

Direct voltage of diode FC rectifier (input voltage of direct current link)

$$U_3 = \frac{\pi}{3} U_2 . \tag{2}$$

Direct voltage of autonomous inverter (output voltage of direct current link)

$$U_4 = K_{\text{cr}} U_3 , \tag{3}$$

where K_{cr} – smoothing factor of direct current link.

Stator winding voltage of drive motor (output voltage of FC autonomous inverter)

$$U_5 = \frac{\sqrt{3}}{2} \mu U_4 , \tag{4}$$

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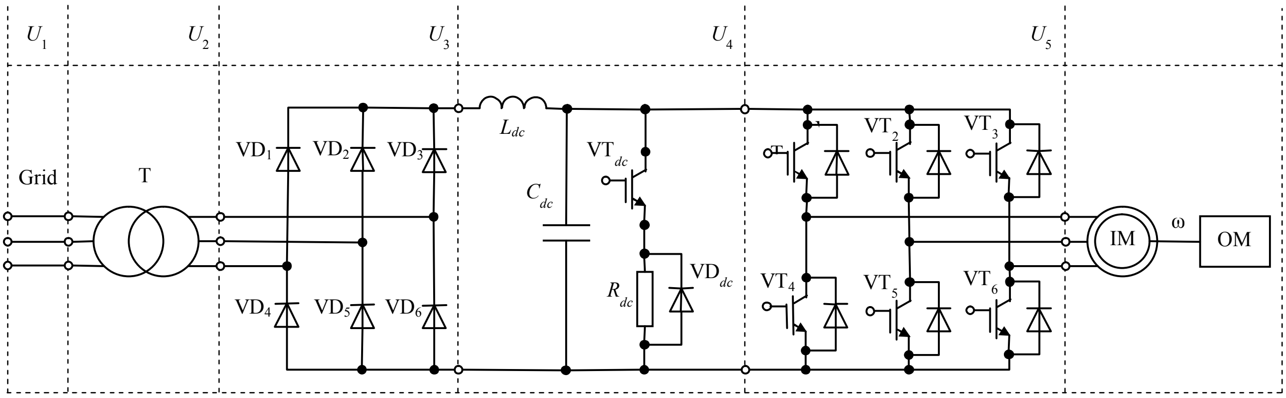

Fig.1. Structural diagram of electric drive with indirect frequency converter

where μ – modulation factor of autonomous inverter.

$$\omega = 2\pi f\ , \tag{5}$$

$$f = \frac{U_5}{K_{con}}\ ,$$

where f – frequency of stator winding voltage in induction motor; K_{con} – proportionality factor of scalar control system,

$$\frac{U_5}{f} = K_{con} = \text{const}\ . \tag{6}$$

Expressions (1)-(6) show, that changes in electric power supply voltage cause rotation frequency changes in induction motor and, as a result, changes of operating modes of operating mechanisms and disturbs technological processes, carried out by them. Voltage oscillations in industrial grids, resulting in negative impact on industrial facilities operation, are caused by followings factors:

- enabling and disabling of uncontrollable electric drives;
- heavy start and stop of electric drives with high torque load;
- starting and stopping of loaded electric drives;
- switching on and off of other loads;
- faults in power supply lines, emergency switching and others.

In order to minimize negative impact of nonregulated voltage distortions on operating modes of electric drives and operating mechanisms several methods could be used [2, 5, 10]. Disadvantages of those methods is in a necessity to install additional equipment, which requires additional investments and results in the complication of electrical energy system structure of industrial facility. Those factors causes increase of operational costs and, in case of low reliability and efficiency of equipment, the defragmentation of electrical energy systems of industrial facility.

Methods of establishing energy compatibility of electric drives and electric power grid are free from those disadvantages [1]. Core of those methods is based on ensuring the energy compatibility by means of modernization of structure and control algorithms of electric drives without changes in structure of electric energy system of industrial facility. In order to eliminate negative impact of electric grid voltage changes on electric drive operation it is required to ensure energy decoupling of electric drive and electric power grid. Let`s examine methods and effectiveness of energy decoupling application in electric drives.

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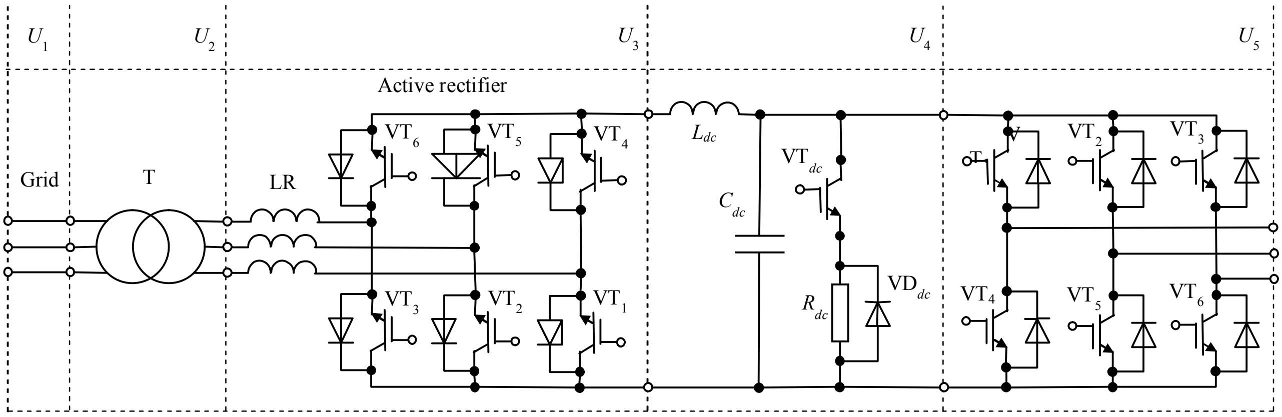

Fig.2. Structural diagram of electric drive with active rectifier in frequency converter

Methodology. Active control systems of power flows, based on fully controlled semiconductor modules, could be used in order to ensure energy decoupling of electric drive and electric power grid. Energy decoupling could be implemented by:

- recuperators of electric energy and function of stabilization of direct voltages in direct current link of electric drive frequency converter;
- active filters of series or parallel types;
- internal electric energy accumulating units of electric drives with direct current converters;
- active rectifiers of frequency converters.

As it is shown in [4, 5, 7, 10, 12], active rectifier of electric drive FC is complex tool to increase the energy efficiency of electrical installation with electric drives and to implement the energy compatibility of electric drive and the grid. The usage of active rectifier allows establishing the supplying and external recuperation of braking energy to electric power grid with satisfactory quality Main advantage of it is in ability to implement energy decoupling of electric drive and electric power grid.

Energy decoupling is a transfer of electric energy from the grid to driving motor without the influence of grid power quality deviations on characteristics and operating modes of motors (and operating mechanisms) of electric drives of industrial electrical facilities. In regards of energy compatibility implementation, active rectifier (AR) removes restrictions, caused by use of uncontrolled diode rectifier (DR), on one-sided transfer of FC energy.

Active rectifier (Fig.2) consists of line reactor and semiconductor assembly. Active rectifier is also provided with control system and set of voltage and current sensor in grid and direct current link capacitor.

Analysis of AR characteristics in order to ensure the energy decoupling was conducted by means of simulation modeling with the use of mathematical application software packages. For research it is required to develop the simulation model with capability to analyze following dependences: voltage amplitude deviation and characteristics of drive motor; voltage frequency deviation and characteristics of drive motor; grid voltage amplitude asymmetry and characteristics of motor; grid voltage phase shift asymmetry and characteristics of motor.

During the research of energy decoupling of electric drive FC and electric grid means, by means of active rectifier, it is practical to make several assumptions, which must accelerate calculation of simulation model and ensure retaining of simulation result coincidence. Generally accepted assumptions during research of electric drive and converters is substitution of semiconductor devices with ideal switches, so that their switching is instantaneous, resistance in open state is equal to zero and is infinite in the closed state.

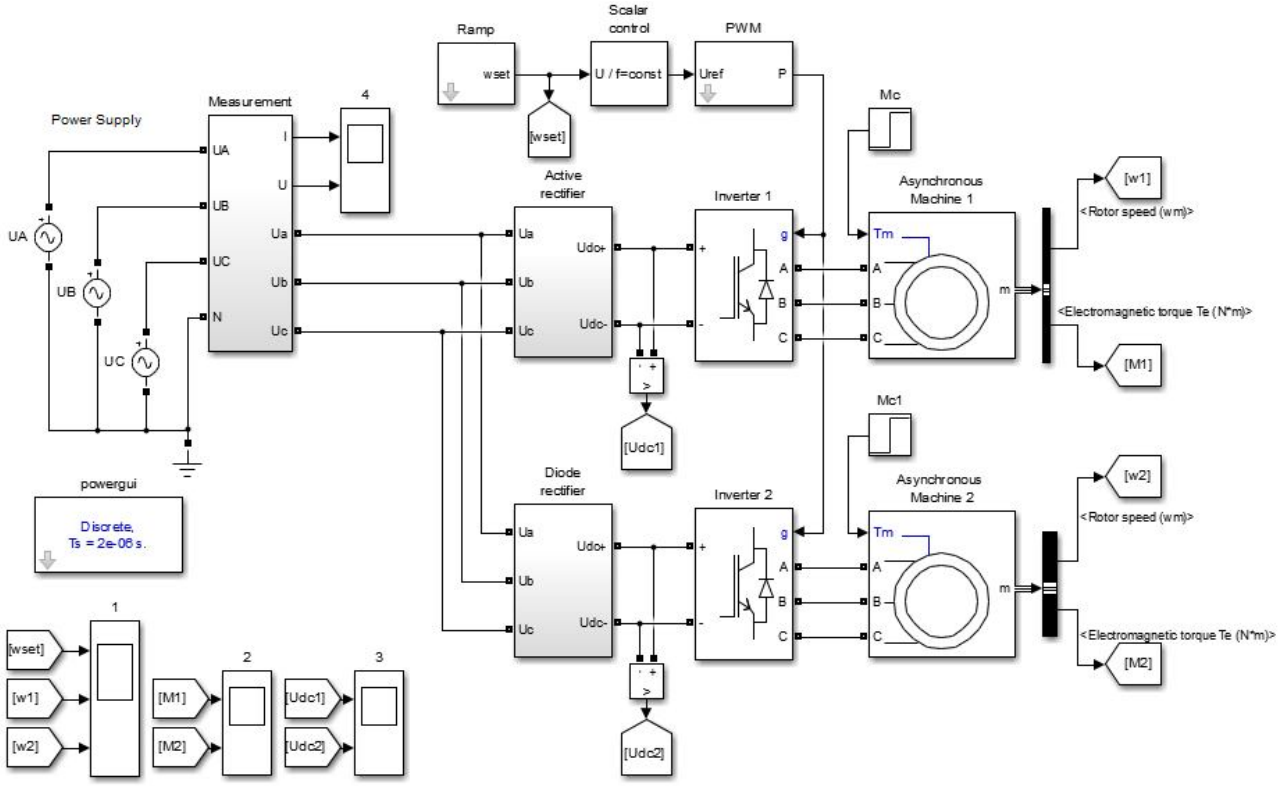

Fig.3. Simulational model for the research of energy compatibility

Simulation model of electric drive with active and diode rectifier in FC and scalar control system is represented in Fig.3. Simulation model is implemented in MatLab environment with the use of blocksets from Simulnk and SimPowerSystems libraries. Formation of simulation model was done in accordance with the following algorithm: formation of equivalent scheme of electric drive; selection of mathematical descriptions of electric drive, implementing previously made assumptions; development of structural diagram, based on mathematical descriptions; realization of structural diagram in MatLab environment.

Simulation model consists of following elements: Power Supply – electric grid; Active rectifier; Diode rectifier; Inverter (1 and 2) – autonomous inverters; Asynchronous machine (1 and 2) – induction motors; Ramp – rate setting device; Load; Scalar control; Pulse width modulation (PWM); Measurement – voltage and current meters.

Simulation model consists of two electric drives – with active and diode rectifiers. Both electric drives are connected to the same electric power system. Control of electric drives is provided by the common scalar control system. Load of electric drives is also the same. The use of common power source, power control and load allows analyzing the abilities of active and diode converters in establishing energy compatibility in same operating conditions.

In order to compare characteristics of active and diode rectifiers while ensuring the energy decoupling of electric drive and the grid, oscillographic testing of following variables was conducted:

- rotation frequency of electric drives with AR and DR, rotation frequency setting;
- torques of induction motors with AR and DR, load torque;
- voltage in direct current link and active rectifier voltage setting;
- voltage of electric power supply system.

Active rectifier has following parameters: supply voltage – 380 V, inductance of reactor – 1 mH, active resistance of reactor – 0,0001 Ohm, output voltage – 600 V, maximum load current – 500 A, capacitance of capacitor – 50000 μF.

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Induction motor with power 75 kW and designed for voltage 380 V was used in electric drives.

Discussion. In order to implement energy decoupling of electric drive and electric power grid it is required to ensure operating mode of drive motor without the influence of electric power supply quality distortions. During the research of energy decoupling simulation of several following operating modes of induction motors was conducted:

• no-load starting to nominal rotation frequency;

• increase of load to nominal on the motor rotating at nominal frequency;

• on-load stop of the motor.

Following oscillograms for alternative current electric drives are represented in Fig.4-6: electric grid voltage (*a*); voltage of direct current link in electric drives with AR and DR, rectified voltage setting for control system of active rectifier (*b*); rotation frequencies of induction motors of electric drives with AR and DR, rotation frequency setting (*c*); torques of induction motors of electric drives with AR and DR, torque setting (*d*).

Oscillograms for electric drives in case of sinusoidal symmetrical grid voltage with line RMS value of 380 V(amplitude phase value 310 V) and frequency 50 Hz are represented on Fig.4.

Analysis of oscillograms shows, that at grid voltage of 310 V, the output voltage of DR is formed at the level of 515 V, while AR ensures maintaining of output voltage at preset value of 620 V. In case when rotation frequency of asynchronous electric drive with DR and load rise in 1 s, deviation of motor rotation frequency is two times higher than in electric drive with AR. Oscillorgram of torque shows that load torque response is faster in electric drive with AR, compared to electric drive with DR. Torque pulsations in the steady-state mode of electric drive with AR are two times lower than in electric drive with DR.

Oscillograms for the case of voltage amplitude reduction to the level of 220 V are represented in Fig.5. This level of decrease corresponds with decrease of electric grid line voltage by 30 % from 380 to 270 V. Oscillograms show that for the case of voltage reduction in electric grid, electric drive with DR is able to ensure speeding-up of induction motor, but in case of sudden load rise the motor stalls. Loss of control is caused by reduction of direct current link voltage to 370 V, which causes the reduction of induction motor flux. Electric drive with AR allows stabilization of voltage at preset level of 620 B. It is also notable, that reduction of voltage by 30 % does not affect operating modes of electric drive.

Oscillograms of electric drive variables for the cases of various amplitude and frequency reductions of voltage in power supply line: U_A = 310 V; U_B = 310 V; U_C = 310 V; f_A = 50 Hz; f_B = 45 Hz; f_C = 40 Hz, are presented in Fig.6.

If electric power supply parameters have these values, pulsations of voltage in direct current link of electric drive with DR are increased, at that, pulsations of rectified voltage are intensify in case of load surge. Oscillograms of rotation frequency show, that operation of motor in electric drive with AR is not affected by electrical energy quality parameters of electric power supply grid. Electric drive with DR is unable to ensure operation during load surge. Load surge cases emergence of significant torque pulsations and significant transient duration of rotation frequency.

Conclusion. Electric drives of industrial facilities ensure the function of main operating mechanisms of technological complexes. Technical operational characteristics of industrial electrical installations, economic viability of exploited mineral deposits and other efficiency factors of industrial objects are depending on their efficient operation. Meanwhile, energy supply of industrial objects is provided with electric energy of low quality, which directly affects the performance of electric drives of main mechanisms. Negative impact may cause deviation of design parameters of electric drives or even cause complete breakdown of main electrical equipment of industrial electric drives.

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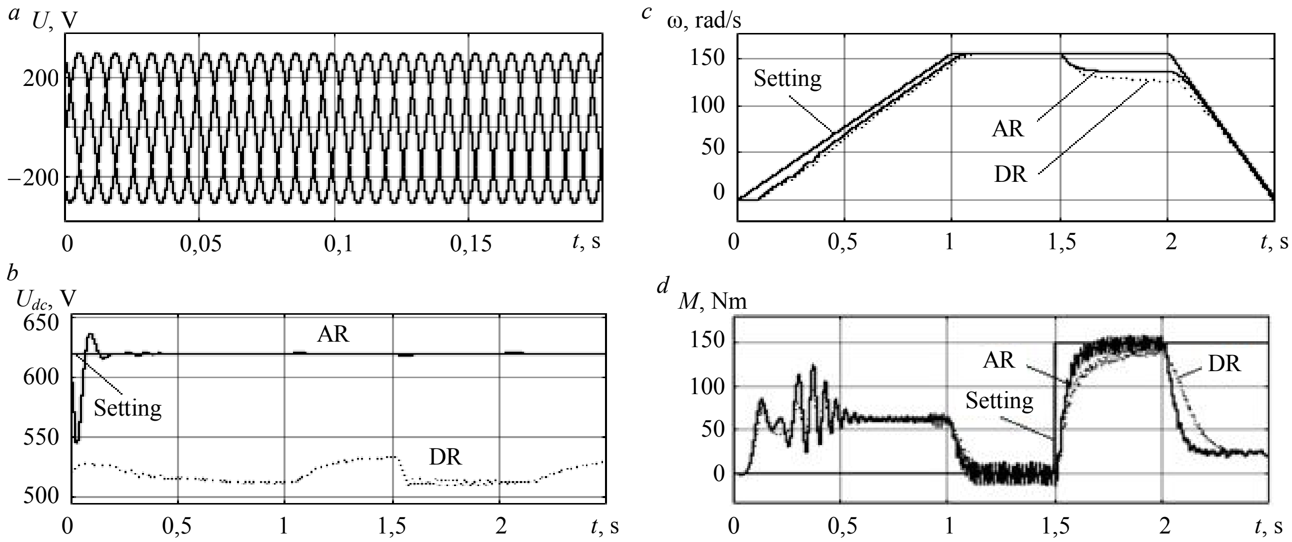

Fig.4. Oscillograms of variables at sinusoidal and symmetrical voltage

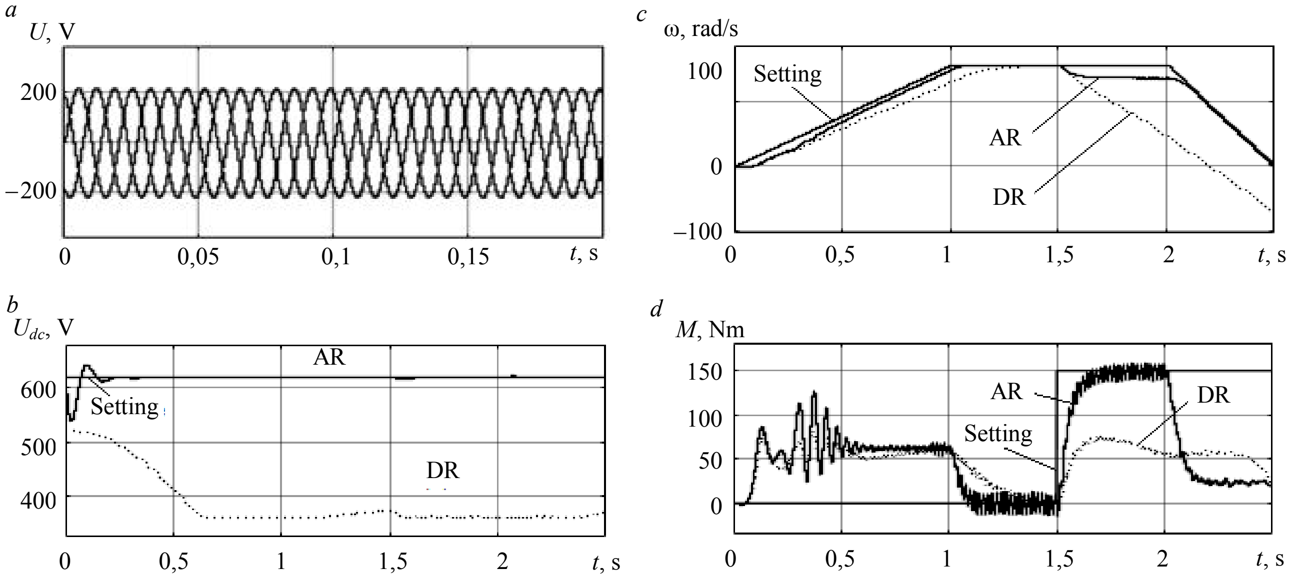

Fig.5. Oscillograms of variables during voltage drops in all phases of the grid

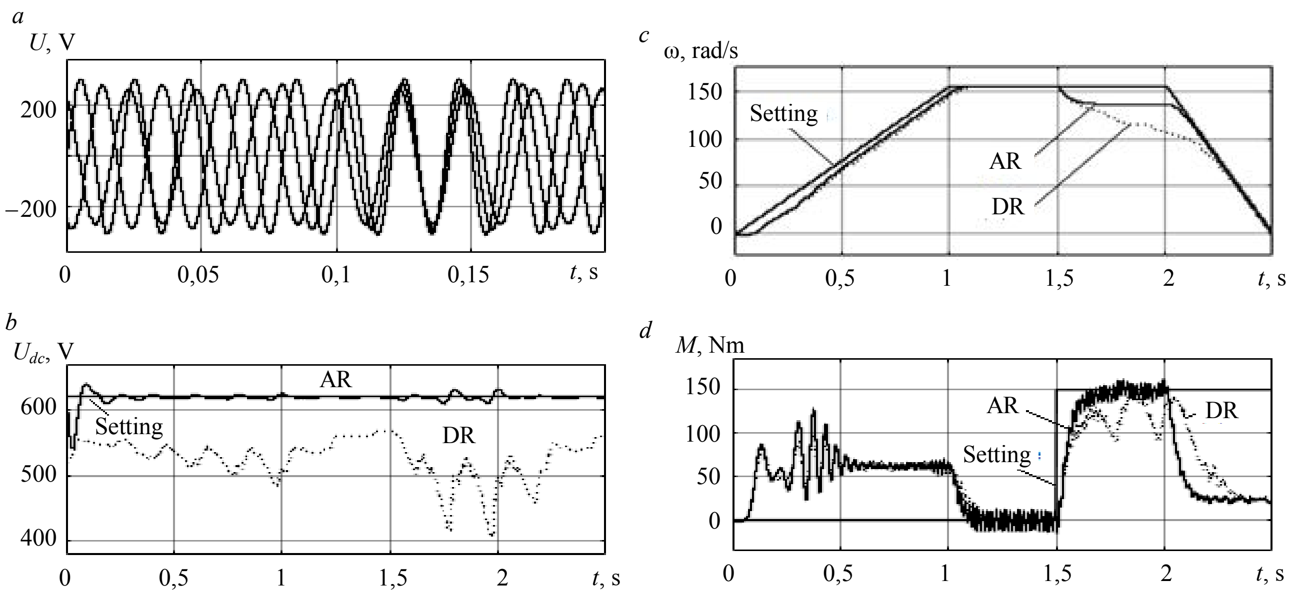

Fig.6. Oscillograms of variables during amplitude and frequency distortions of voltage in phases of the grid

It is reasonable to establish energy decoupling of electric drives of main electrical installations and electrical energy grid in order to eliminate negative impact. Most effective methods of ensuring the energy decoupling are internal means of electric drives. Their usage does not require modernization of electric power supply grids and installation of additional equipment. Most effective means of implementation of energy decoupling are active rectifiers of frequency converters of alternative current electric drives.

Research of effectiveness of energy decoupling, provided by means of frequency converter with active rectifier, shows that in case, when power quality parameters of electrical grid are changing, driving motor fully maintain stability and controllability of rotation frequency and torque. The use of active rectifier allows ensuring the operation of electric drive in preset mode during voltage drops by 30 % with normative value of 5-10 %, i.e. energy decoupling provides high stability margin for voltage. Electric drive with active rectifier ensures energy decoupling in case of asymmetry of supply voltage. The Control of mechanical variables of inductor motor during distortions of amplitude and frequency in all phases of electric grid is ensured to be on required level.

Performed research shows that it is impossible to ensure the operation of electric drive during changes of power quality parameters in electric grid without the use of energy decoupling. The examination of electric drive with diode rectifier shows that. Establishing of energy decoupling of electric drives and electric power supply grids currently is a major factor in ensuring of not only technical operational characteristics of electric drives, but of whole complex of electrical equipment of industrial facilities.

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