Automatic control in multidrive electrotechnical complexes with semiconductor converters

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Abstract. The frequency converter and the automatic control system, which can be used in the multi-drive electromechanical system with a few induction motions, are considered. The paper presents the structure of existing modern multi-drive electric drives inverters, namely, electric drives with a total frequency converter and few electric motions, and an electric drive, in which the converter is used for power supply and control of the independent frequency. It was shown that such technical solutions of frequency converters possess a number of drawbacks. The drawbacks are given. It was shown that the control of technological processes using the electric drive of this structure may be provided under very limited conditions, as the energy efficiency and the level of electromagnetic compatibility of electric drives is low. The authors proposed using a multi-inverter structure with an active rectifier in multidrive electric drives with induction motors frequency converters. The application of such frequency converter may solve the problem of electromagnetic compatibility, namely, consumption of sinusoidal currents from the network and the maintenance of a sinusoidal voltage and energy compatibility, namely, consumption of practically active energy from the network. Also, the paper proposes the use of the automatic control system, which by means of a multi-inverter frequency converter provides separate control of drive machines and flexible regulation of technological processes. The authors present oscillograms, which confirm the described characteristics of the developed electrical drive. The possible subsequent ways to improve the multi-motor drives are also described.

1. Introduction
A modern electrical drive of industrial factories is generally a multi-motor electromechanical system (MMES), which can be partly or fully regulated. In the most cases, the bases of such systems are an induction motor and a power semiconductor frequency converter. Induction motors are widely used in case of their simple construction, high reliability, low cost and the possibility of regulation of the frequency and the force moment using simple technical devices [1-6].

For regulating the frequency of rotation of asynchronous motors, a generic two-tier frequency converter, which consists of an uncontrolled rectifier diode and a transistor fully managed by an autonomic inverter, is widely used. The main disadvantage of induction motors is a low capacity factor. The block diagram of the multi-inverter electromechanical system (MIES) with asynchronous motors and a shared frequency converter, which has become widespread in industrial factories, is shown in figure 1 (power supply system – PSS; transformer – T; line reactor – LR; motor reactor – MR; diode rectifier – DR; active rectifier – AR; direct current link – DCL; inverter – I; induction motor – IM; chopper - Ch).
The frequency convertor and the automatic control system, which can be used in the multidrive electromechanical system with a few induction motions are considered [7-10]. The paper demonstrates the structure of existing modern multidrive electric drives inverters, namely, the electric drives with a total frequency convertor and few electric motions, and an electric drive, in which the converter is used for power supply and control of the independent frequency.

The authors show that such technical solutions of frequency converters possess a number of drawbacks. The drawbacks are the following. The control of technological processes, using the electric drive of this structure, may provide very limited conditions. Energy efficiency and the level of electromagnetic compatibility of electric drives are also low. The use of frequency converters of the multiinverter structure with an active rectifier is proposed in multidrive electric drives with induction motors. The application of such frequency convertor solves the problem of electromagnetic compatibility, namely, consumption of sinusoidal currents from the network and maintaining a sinusoidal voltage, and energy compatibility, namely, consumption of virtually active energy from the network. In addition, the authors proposed the automatic control system which, by means of the multiinverter frequency convertor, provides separate control of drive machines and flexible regulation of technological processes. The oscillograms which confirm described characteristics of the developed electrical drive are shown. The possible subsequent ways to improve the multi-motor drives are described.

The shared frequency convertor has some disadvantages. A diode rectifier makes a significant negative effect, which is characterized by a low level of electromagnetic compatibility with the power supply network, which is expressed as follows:

- High value of the distortion voltage power supply and the current consumption
- Low capacity factor of the electric drive;
- Unilateral conductivity of the rectifier;
- Low efficiency of the transformer;
- Significant ripple voltage of the direct current (DC) line.

Another negative effect is a technological effect, relative to the overall control system, which is able to provide only synchronous (simultaneous and identical) control of mechanical coordinates of asynchronous motors.

This power and technological disadvantages represent the actual task for making a new-kind of frequency convertor, which is able to provide a high level of electromagnetic compatibility, the unit power factor of a multi-motor electric drive and effective control of separate motors.

2. Materials and methods

Power problems of the multiengine electromechanical system can be solved by using a frequency convertor with an added active rectifier. Usually, the power scheme of the frequency convertor with an active rectifier is unified with the scheme of the autonomous inverter. Therefore, it is made in the same way as an autonomous inverter. When using the active rectifier on the frequency convertor, it is advisable to use chokes instead of a transformer.
Active rectifier control system and the automatic inverter, based on an algorithm executed by pulse-width modulation (PWM), are also standardized. Through the use of the PWM mode, a voltage generated active rectifier on the alternating current (AC) side, has a favorable harmonic composition in which the main (useful) harmonic and higher harmonics differ significantly in frequency. This increases the efficiency of harmonic filtering of the current consumed from the power supply network, and a line choke. Thus, we consume almost sinusoidal current out of the electrical network.

The phase angle of the current consumption depends on the ratio of amplitudes and phase angles of the voltages applied to the line chokes from the mains, as well as their parameters. The control system can change the parameters of the fundamental harmonic of the AC voltage. That is why, it is able to provide the necessary consumption of current with a predetermined phase angle from the network. In other words, we can force the frequency converter to work with a given value of the power factor, for example, equal to one, as well as the «leading» or «lagging» power factor.

As energy is converted from DC to AC by the power inverter, there is a self-contained extremely valuable property - the possibility of bilateral energy exchange between networks AC and DC. This property is preserved in the reverse connection circuit of the autonomous inverter as an active rectifier. As a result, a two-tier frequency converter with an active rectifier provides two-way exchange of energy between the power supply and the electric motor, including modes of energy recovery in the mains supply.

Technological problems of MIES, i.e. provision of each of the electric induction motors with individual control, can be solved by using a multi-inverter frequency converter. Each inverter forms the stator windings on the drive motors with specified voltage, amplitude and frequency, and has an autonomous control system that allows adjusting the coordinates of each electromechanical motor MIES individually. All inverters of the converter are connected to a common active rectifier, which maintains a constant voltage DC bus and the level of electromagnetic compatibility with the power supply network at a given level.

The technological installation of water supply in energy stations is an example of MMES. These installations are either unregulated, that is pump drive motors are connected directly to the mains, or use a common frequency converter for the implementation of the general control of all drive motors of water supply pumps.

The functional scheme of MMES of technological water supply of the energy station is shown in figure 2, which includes a multi-inverter frequency converter with the active rectifier and individually controlled electric drive and pumps. Three pumps and three induction motor are used in the technological installation of water supply. The main technical specifications of the pumps and the motors are given in tables 1 and 2, respectively. The following abbreviations are used in figure 2: pump – P; control system – CS; technological control system – TCS; Q1*, Q2*, Q3* – set flow; Q1, Q2, Q3, Q – real flow; ω1*, ω2*, ω3* – set speed of IM; ω1, ω2, ω3 – real speed of IM; εQ – flow error ; S1*, S2*, S3* – switching function of I; U1*, U2*, U3* – set voltage of IM.
Individual control is carried out by each motor. The motor control system provides vector control of each IM. The voltage on windings of the IM stator is formed by the inverter with pulse-width modulation. Set flow ($Q^*$) is the input control action for the technological CS. Technological CS must generate the set flow for each pump ($Q_1^*$, $Q_2^*$, $Q_3^*$), according to the task of the set flow of technological installation ($Q$).

The water flow consumer changes from 0 m$^3$/h to 390 m$^3$/h. The speed of each IM changes from 0 rpm to 2900 rpm. The set speed of each IM is formed according to the following algorithm:

1) If the set flow varies $0 < Q^* \leq 130$, the set:
   - flow of P1: $Q_1^* = Q^*$; speed IM1: $0 < \omega_1^* < 1.3 \omega_{nom}$;
   - flow of P2: $Q_2^* = 0$; speed IM2: $\omega_2^* = 0$;
   - flow of P3: $Q_3^* = 0$; speed IM3: $\omega_3^* = 0$.

2) If the set flow varies $130 < Q^* \leq 230$, the set:
   - flow of P1: $Q_1^* = Q_{nom}$; speed IM1: $\omega_1^* = \omega_{nom}$;
   - flow of P2: $Q_2^* = Q^* - Q_{nom}$; speed IM2: $0 < \omega_2^* < 1.3 \omega_{nom}$;
   - flow of P3: $Q_3^* = 0$; speed IM3: $\omega_3^* = 0$.

![Diagram](image_url)

**Figure 2.** The block-diagram of the electrical drive with multi-inverters of the frequency converter.

**Table 1.** Technical specifications of the pumps

| Parameters               | Values  |
|-------------------------|---------|
| Nominal flow (m$^3$/h)  | 100     |
| Nominal head (m)        | 80      |
| Range of flow control (%)| 30 to 130 |
| Nominal power (kW)      | 32.5    |
| Nominal efficiency (%)  | 67%     |
**Table 2. Technical specifications of the induction motor**

| Parameters          | Values |
|---------------------|--------|
| Nominal power (kW)  | 45     |
| Nominal speed (rpm) | 2900   |
| Nominal current (A) | 84.9   |
| Nominal efficiency (%) | 92   |
| Nominal power factor (pu) | 0.89 |

3) If the set flow varies \(230 < Q^* \leq 330\), the set:
- flow of P1: \(Q_1^* = Q_{\text{nom}}\); speed IM1: \(\omega_1^* = \omega_{\text{nom}}\);
- flow of P2: \(Q_2^* = Q_{\text{nom}}\); speed IM2: \(\omega_2^* = \omega_{\text{nom}}\);
- flow of P3: \(Q_3^* = Q^* - Q_{\text{nom}}\); speed IM3: \(0 < \omega_3^* < 1.3 \omega_{\text{nom}}\).

4) If set flow varies \(330 < Q^* \leq 390\), the set:
- flow of P1: \(Q_1^* = \frac{Q_{\text{nom}}}{3}\); speed IM1: \(\omega_{\text{nom}} < \omega_1^* < 1.3 \omega_{\text{nom}}\);
- flow of P2: \(Q_2^* = \frac{Q_{\text{nom}}}{3}\); speed IM2: \(\omega_{\text{nom}} < \omega_2^* < 1.3 \omega_{\text{nom}}\);
- flow of P3: \(Q_3^* = \frac{Q_{\text{nom}}}{3}\); speed IM3: \(\omega_{\text{nom}} < \omega_3^* < 1.3 \omega_{\text{nom}}\).

With such kind of control, the number of working motors will be adjusted to the consumption. As a result, the flow rate job is higher than that which can be provided for each of them.

MIES provides an optimal scalar control law of the induction motor, and the voltage at the stator windings formed by the PWM control algorithm. By selecting the required number of working pumps and motors and ensuring their optimal operation, minimal power consumption and a constant water flow at the inlet of the consumer will be supported.

3. Results and Discussion

The study of the effectiveness of the proposed technical solutions in the power part of the drive and control modes of asynchronous motors of MIES was carried out in MatLab.

Oscillograms of phase voltage and current consumed by the electric drive are shown in figure 3 (a). Oscillograms of active and reactive power consumed by the electric motor during acceleration and steady-state conditions are shown in figure 3 (b). As seen from the waveforms, the use of active rectifier supports the MIES without any negative impact on the shape of main electricity supply and consumption of MIES with induction motors having sinusoidal currents. Also, it is clear that the use of the active rectifier inverter forces the multi-inverter to consume almost purely active power. These two factors ensure the unified operation of the drive power factor.

Figure 4 (a) shows a waveform of the current setpoint and the water flow at the inlet of the consumer; in figure 4 (b), one can see the current speed of the drive induction motors. It can be seen out of waveforms that the flow control forms at high accuracy, the probability of a static error is practically zero. Transients of the flow rate are proceeding monotonically, without overshoot. The speed control of induction motors is also implemented with high precision in both dynamic and steady-state modes.
4. Conclusion

Research and development of various structures and control system for multimotor electric drives with semiconductor converters are of great importance. The importance is determined both by the high energy consumption of electric drives, great energy saving potential and complexity of technical and algorithmic decisions for providing flexibility of production units (with electric drives) of control systems.

Taking into consideration the latest development in the field of semiconductors, microprocessor-based control systems and their algorithms, the electric drives with energy saving asynchronous motors, a multi-inverter converter structure and a vector control system with intellectual technological control systems are the main technical decisions for technological processes of automation. The latest researches show that such technical decisions provide reliability and flexibility of control systems, minimize the influence on supply systems and improve energy efficiency due to using energy saving drives and unity power factor provided for groups of asynchronous drives.

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