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Application of Modern Electric Drive Control Technologies to Increase Efficiency in Energy and Industry

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ABSTRACT

The use of modern electric drive control technologies in the energy sector and industry can significantly improve the efficiency of production processes. The main goal is to optimize the operation of the equipment and reduce energy consumption. The methodology includes the use of intelligent control algorithms, frequency converters, and adaptive systems, which allow precise control of the operation parameters of electric drives. The results show that the introduction of digital systems and artificial intelligence elements reduces energy consumption by up to 30%, increases equipment productivity, and prolongs its service life. The findings confirm that modern electric drive control systems are key to improving efficiency and reliability in production processes. These technologies contribute to the sustainable development of energy and industrial enterprises, creating conditions for saving resources and improving safety.

KEYWORDS: *electric drives, frequency converters, adaptive control, energy saving, industrial automation, intelligent systems.*

INTRODUCTION

The current development of energy and industry demands the implementation of advanced technologies aimed at increasing efficiency and reducing energy consumption. Amid global challenges such as rising energy prices and the need to reduce carbon emissions, electric drive management has become a key aspect of optimizing production processes. Electric drives are used in a wide range of applications, from controlling pump systems and compressors to operating ventilation systems and transport mechanisms. Their integration improves the quality and speed of technological operations, ultimately leading to lower operating costs and increased profitability for enterprises.

The relevance of this topic is driven by the growing interest in sustainable development and enhancing the efficiency of industrial processes. The implementation of intelligent control systems, frequency converters, adaptive algorithms, and modern digital technologies creates new opportunities for managing electric drives. This, in turn, not only improves the accuracy of parameter regulation but also minimizes risks associated with breakdowns and accidents. The application of such technologies has become an integral part of enterprise modernization and digital transformation strategies.

The purpose of this study is to investigate modern technologies for electric drive management and their impact on improving efficiency in energy and industry.

MATERIALS AND METHODS

Electric drive control systems perform several essential functions, including starting, speed variation, braking, changing rotation direction, and maintaining a specific operating mode aligned with the technological process requirements [1]. To ensure maximum performance and minimize both capital and operating costs, such as electricity consumption, it is crucial to consider the design features of the machinery and the types of electric drives. This is necessary for developing, designing, and analyzing the electric drive control system, taking into account the specific operating conditions and the equipment's intended purpose [2].

Control systems are also classified based on their functions. The first group includes systems for starting, stopping, and reversing, typically used in drives that do not require speed regulation, such as pumps and fans. The second group allows speed control and is applied in mechanisms with variable loads, such as transport vehicles. The third group adds the capability to maintain parameters (e.g., speed, current) under changing conditions, often using feedback mechanisms for regulation. The fourth group of systems is designed to track parameters that vary in real-time. The fifth group comprises programmed systems that control machines based on predefined algorithms. The sixth group combines all the aforementioned functions, providing optimal mode selection through computational systems for analysis and control.

Automatic control systems are further classified by the types of devices used: relay, magnetic, semiconductor, and others. The primary requirements for these systems include maintaining the operating mode, simplicity of design, reliability, and cost-effectiveness. Additional requirements may include explosion safety, vibration resistance, and noise reduction [3].

In turn, electric drives are an integral part of energy and industrial systems, facilitating motion control and energy transfer from the source to the actuators. They consist of an electric motor and a control system, which allows for the regulation of operational parameters such as rotational speed, torque, and direction of motion. Depending on the task and specific production process characteristics, electric drives can be utilized in various configurations and power ratings, making them a versatile tool in modern industrial installations.

In the energy sector, electric drives are employed to control generators, pumps, fans, and other mechanisms, ensuring high precision in regulation and minimizing energy losses. They play a crucial role in maintaining the stability of power systems and enhancing their efficiency. A significant aspect is that modern electric drives can integrate with automation systems, providing flexible and adaptive real-time control.

In industry, electric drives are used to automate production processes, such as conveyor systems, machine tools, and robotic complexes. They provide precise control of movement and positioning, improving product quality and reducing production cycle time. Furthermore, electric drives contribute to increased energy efficiency in production processes, as modern technologies allow them to adapt their operation to changing conditions and requirements.

The rapid advancement of microprocessor technologies has led to the integration of digital controllers in electric drive control systems. This innovation expands the range of applicable laws and algorithms, both linear and nonlinear, significantly enhancing device control and precision. However, digitalization introduces certain characteristics specific to such systems, including the pulse nature of information. This manifests in temporal and level discreteness, as well as delays in the control channel due to data processing and signal generation.

These developments necessitate the creation of new control algorithms and system synthesis methods. Modern digitally controlled electric drives operate based on these principles and possess a set of characteristic properties, which will be described in Table 1.

Table 1. Principles and characteristics based on which modern electric drives work [4]

Characteristic	Description
High arithmetic and logical power	Enables the implementation of complex control algorithms, including linear and nonlinear models, functional extrapolation, transcendental dependencies, and coordinate transformation for multi-linked electric drive systems.
Available memory	Allows for the consideration of accumulated information to form relevant control actions, enabling the system to adapt to changing operating conditions.
Programmability	Facilitates the creation of multi-mode and multifunctional systems based on microprocessor technology, providing flexibility and adaptability to various tasks and operating conditions.

The construction of a BLDC motor resembles that of a PMSM, though it is not identical. When examining their differences, it can be noted that the BLDC device is similar to the PMSM but has distinctive features. Permanent magnet synchronous motors can operate in two modes, which will be shown in Figure 1.

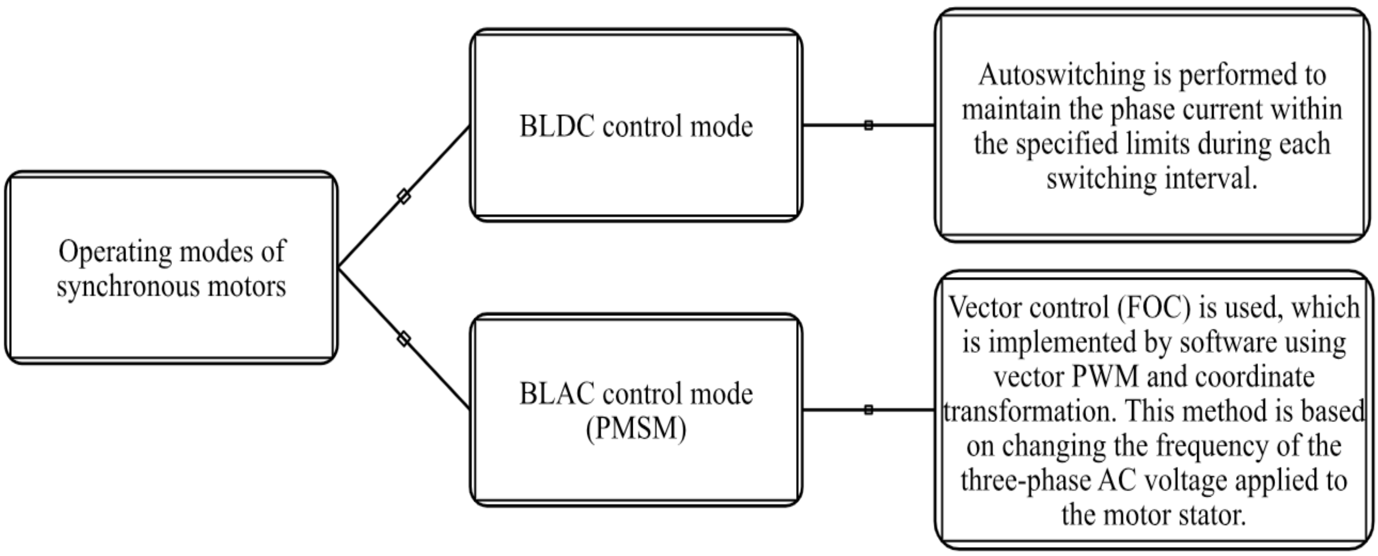

Fig.1. Operating modes of synchronous motors [5]

In both types of motors, the rotor is equipped with permanent magnets, and a rotating magnetic field created by the stator is required to generate torque and drive the rotor. In a BLDC motor, a constant voltage is applied to the inverter, with current flowing through only two phases at any given time.

To implement a 6-sector PWM, six combinations of transistor switch activations must be cycled to complete a full magnetic rotation cycle. The difference between mechanical and electrical rotations depends on the number of motor poles and is expressed by the formula

$$n_{mag} = p \times n_{mech} \qquad (1)$$

where p represents the number of pole pairs.

Speed regulation requires precise rotor position determination, which can be achieved with sensors (e.g., Hall sensors, encoders) or sensorless methods (using the back EMF of the stator windings) [5].

Modern electric drive control technologies play a crucial role in increasing efficiency in energy and industry. Electric drives, as the foundation of many industrial processes, provide precise control over motion, speed, and torque, optimizing equipment performance and reducing energy costs. Recent developments include the implementation of intelligent control systems that can automatically adapt to changing working conditions, minimizing energy losses and enhancing overall productivity.

One such approach is the use of frequency converters, which adjust motor speed based on current loads and production process requirements. Frequency regulation significantly reduces energy consumption by maintaining an optimal operating mode, also extending equipment lifespan. Additionally, real-time monitoring and diagnostic systems enable the rapid detection of faults and deviations in electric drive operation, preventing potential accidents and reducing repair costs.

Another key aspect is the integration of electric drives with automation and production process management systems (SCADA and MES systems). This integration provides centralized control and monitoring of equipment operation, increasing production flexibility and adaptability. Consequently, the application of modern electric drive control technologies significantly improves energy efficiency and productivity, ensuring sustainable development and competitiveness in a rapidly evolving industrial landscape [6].

Thus, modern electric drive control technologies have a substantial impact on enhancing productivity and efficiency in industry and energy, supporting sustainable development and competitiveness for enterprises.

RESULTS AND DISCUSSION

In modern technological conditions, where efficiency, precision, and sustainability are key factors, electric drives remain a crucial element in the operation of various industrial and household systems. These devices, which convert electrical energy into mechanical action, have long contributed to progress and innovation across numerous industries.

However, with increasing demands for efficiency, reliability, and sustainability, the development of electric drive technologies has become inevitable. New drive solutions for industrial machinery and mechanisms are now available on the market, providing increased operating speeds, improved energy efficiency, and high reliability. These technologies can be classified as follows:

- Variable frequency drives (VFDs) using the U/f method

- Vector-controlled variable frequency drives (VFDs)

- Electric servo drives

Modern drives, such as servo drives, incorporate complex electronic control systems and are more expensive than conventional fixed-speed electric motors.

Variable frequency drives, also known as frequency-controlled drives, are used with AC induction motors. The scalar control method (U/f) allows for frequency adjustment of the output signal through a frequency converter, which affects the motor's rotational speed. The voltage-to-frequency ratio enables optimal torque maintenance within specified operating ranges. These drives are economically advantageous, although their accuracy is limited to approximately 10% under varying loads. This method has been widely used to control industrial machines and mechanisms for many years.

Under constant load conditions, drive accuracy remains high and can be improved using a tachometer. However, dynamic characteristics are limited, making this type of drive less suitable for processes requiring quick responses to load changes. Additionally, there is a speed limit of 400–500 revolutions per minute. Despite these limitations, such drives remain in demand due to their ability to effectively control speed and torque.

Servodrives represent an advanced stage in drive system development, utilizing permanent magnet motors with minimal inertia. These systems provide maximum torque even at zero speed, enabling highly dynamic processes. Their control requires a complex system, which is justified by the high precision of speed, torque, and shaft position control. It is important to note that under high load conditions, servo drives may require additional cooling systems and are limited in power, necessitating the use of multiple drives to meet high-demand tasks.

Table 2. Comparison of the main parameters of three types of electric drives [7]

Parameter	VFD with scalar control	VFD with vector control	Servo drive
Control accuracy	Moderate	High	Very high
Dynamic characteristics	Moderate	High	Very high
Initial torque	Moderate	High	Very high
Energy efficiency	Medium	High	Very high
Cost	Medium	High	High
Application	Broad, best for standard tasks	Diverse, including complex tasks	High-dynamic and precise tasks

Table 2 provides a general comparison of the main parameters of the three types of electric drives, helping to determine which is best suited for specific requirements. When selecting equipment from a supplier, these factors should be considered. This aspect is especially relevant for enterprises upgrading their machinery and companies implementing new equipment based on advanced technologies [5]. The following section discusses examples of implementation at enterprises in Ukraine.

For instance, at power plants such as the Kyiv Pumped Storage Power Plant (PSPP), implementing a variable frequency drive (VFD) for pump control has optimized equipment operation and reduced operating costs. Installing such drives decreases peak loads on power grids and reduces energy consumption through more precise pump control, based on the water demand for pumped storage [8]. At the Mariupol Metallurgical Plant, an electric drive control system based on programmable logic controllers (PLC) was implemented for steel rolling processes. This system significantly reduced manual labor and improved the accuracy of process control, resulting in increased production volumes and reduced energy costs [9].

Thus, modern electric drive control technologies have a significant impact on efficiency in both energy and industry. Examples and statistical data show that implementing intelligent systems, frequency converters, and automated monitoring systems not only reduces energy consumption but also enhances equipment productivity and reliability. These examples underscore the importance of innovations for the sustainable development of Ukraine's energy and industrial sectors.

CONCLUSION

The conducted research has established that the application of modern electric drive control technologies significantly enhances efficiency in the energy and industrial sectors. Implementing intelligent systems, such as frequency converters and adaptive algorithms, ensures high precision and flexible control, allowing for equipment optimization, energy cost reduction, and minimization of breakdown and accident risks.

Digitalization and the use of artificial intelligence elements in control systems facilitate process automation, improve equipment monitoring and diagnostics, and extend equipment lifespan. Examples of technology implementation at enterprises have demonstrated that such approaches not only reduce operating costs but also improve productivity and product quality. Thus, modern electric drive control technologies play a key role in the sustainable development of the energy and industrial sectors, ensuring economic efficiency and safety of production processes.

The findings confirm that further development and integration of these technologies will contribute to enterprise optimization, increased competitiveness, and reduced environmental impact.

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