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Trends and New Challenges in the Energy Efficiency of Electric Machines

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ABSTRACT
The article is devoted to an overview of modern challenges and changes in the field of both the legislative framework and in matters of ensuring the energy efficiency of electric machines. The main methods of increasing the efficiency of electromechanical converters and new types of materials used in machines of this type are investigated. Particular attention is paid to the economic consequences and reasons for the transition to highly energy-efficient electrical machines, as well as the introduction of special electrical machines in serial and mass production.

Keywords: *Energy Efficiency Class, Efficiency, Electric motor, Energy Efficiency.*

1. INTRODUCTION

Energy plays a central role in life of every person and in the development of world economy. An increase in population, an increase in the well-being of countries and citizens lead to an increase in the production of goods, which increases the need for electricity.

At the end of 2020, total installed capacity of power plants of the UES of Russia amounted to 245.31 GW [1].

Electricity generation by power plants of the Russia UES in 2020 amounted to 1,047.03 billion kWh. Electricity consumption in 2020 amounted to 1,033.72 billion kWh.

The annual maximum power consumption of the Russia UES was 150 434 MW. At the same time, the load of power plants of the UES of Russia amounted to 151,962 MW.

Figure 1 shows the world's energy consumption statistics. As can be seen from the graph, each year the increase in energy consumption is approximately 1 billion kWh.

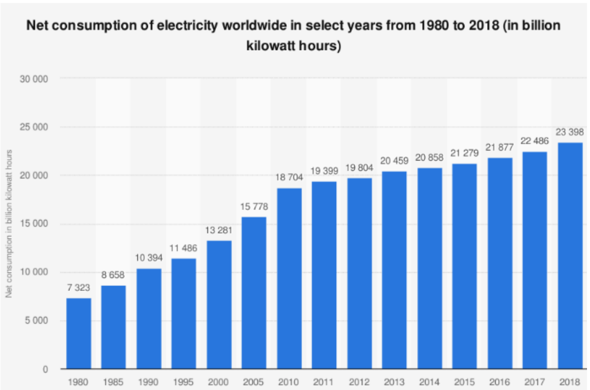

Figure 1 World energy consumption.

The essence of the global problem facing modern human civilization is the contradiction between the ever-increasing needs of mankind for resources and a decrease in their reserves. This primarily refers to mineral and energy resources [2].

Due to the fact that in recent decades, for objective reasons, both natural resources of minerals and the impact of civilization on Earth's ecosystems are constantly being audited, most countries have come to understand that economic and environmental considerations require all-around and widespread saving of energy resources. Such savings make it possible to reduce production costs, save energy resources for future generations, and reduce environmental pollution. Possible solutions to this problem:

• creation and use of resource-saving industrial technologies;

• complete extraction of minerals from the bowels of the Earth (for example, the oil recovery factor with modern production methods is 0.25–0.45);

• use of secondary raw materials [2].

Thus, against the background of such global trends as globalization, urbanization, demographic changes, climate change, a number of acute problems in the field of energy can be identified: depleting reserves, rising energy prices, increasing energy consumption, increasing environmental pollution (increasing carbon dioxide emissions).

In 2020, the Energy Strategy of Russia until 2035 was adopted. The goal of new strategy is to achieve a structurally and qualitatively new state of the energy sector, which will maximally contribute to the dynamic socio-economic development and ensure the national security of the Russian Federation. The main directions of this strategy are digital transformation, optimization of the energy infrastructure, and reducing the negative impact of the fuel and energy complex industries on the environment. To this end, Energy Strategy provides for increasing the efficiency, reliability, availability, and quality of meeting domestic demand for all energy resources, technologies, and services in the energy sector.

The share of electric drive systems and electric motors accounts for about 70% of the total electricity consumed by the industry, therefore, increasing the energy efficiency of the motor, taking into account the conditions of its use, is a necessary task within the framework of energy strategy implementation [4]. In the order of the Government of the Russian Federation of December 27, 2010 No. 2446-r, plans were introduced to ensure energy efficiency. This regulation sets out plans to replace old electric motors with energy-efficient ones, and the primary objective was to replace 48 % of existing motors with energy-efficient ones and 28 % with energy-efficient motors.

It should also be noted that it is an integrated approach that is the key to sustainable energy efficiency, that is, optimization at all levels brings the greatest effect – the contribution from the use of an energy-efficient motor can be further increased if the complete system is modernized, as well as adapted for a specific process.

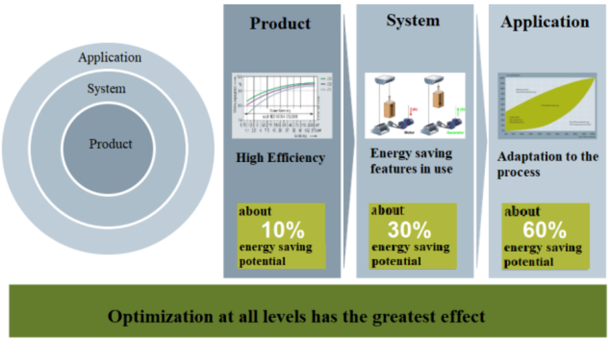

Figure 2 An integrated approach to energy efficiency.

2. THE CONCEPT OF ENERGY EFFICIENCY

Energy efficiency is understood as a set of characteristics reflecting the ratio of the beneficial effect of using energy resources to the costs of energy resources produced in order to obtain such an effect, in relation to a product or a technological process [5].

The electric motor, in the process of energy conversion, loses part of it in the form of heat. The amount of losses of an electric motor is determined by its design parameters, as well as materials that affect the electromagnetic parameters of the electromechanical converter.

The main indicator of the energy efficiency of an electric motor is its efficiency. The energy efficiency of an electromechanical converter should be understood as the efficiency curve in relation to the net power at which the motor operates.

$$\eta = \frac{P_2}{P_1} = 1 - \frac{\Delta P}{P_1} \quad (1)$$

where P_2 – mechanical power on the motor shaft, P_1 – active power consumed by the electric motor from the network, ΔP – total losses arising in the electric motor.

3. OVERVIEW OF EXISTING STANDARDS

At the moment, the introduction of energy-efficient motors allows: to increase the efficiency of the motor by 1-10%; to increase the reliability of the motor; reduce downtime and maintenance costs; increase the motor's resistance to thermal loads; improve overload capacity; increase the motor's resistance to various violations of operating conditions: undervoltage or overvoltage, phase imbalance, etc.; increase the power factor; reduce the noise level [5].

An important tool for the systematic improvement of working properties and accelerating the introduction of new energy-efficient systems are international and state standards that introduce energy classification of equipment, establish the boundaries of efficiency classes and standardize the test procedure for determining whether equipment belongs to one of these classes. In a number of countries (European Union, China, Japan, USA) such standards are the main by-laws requiring the mandatory use of energy-saving equipment in newly commissioned installations and buildings, as well as giving certain benefits when using such equipment [6].

Since the beginning of 2000 energy efficiency standards are gradually being introduced for electric motors and electric drive systems. In the world, there are several global commissions for the standardization of electrical products, which have their own standardization system. Among the most significant are the standards of the International Energy Commission (IEC) and NEMA (National Electrical Manufacturers Association) standards. NEMA standards are in effect primarily in the United States [6].

On July 1, 2021, a new international standard IEC 60034-30 was introduced. The IEC 60034-30-1 standard specifies energy efficiency classes (IE classes) for three-phase and single-phase AC motors with the direct mains supply. The standard applies to asynchronous and synchronous reluctance motors [6].

In the past, globally applicable efficiency classes and a series of energy efficiency regulations have been drawn up to determine the energy efficiency of a motor, which are summarized under the title of green design or European regulation. The efficiency classification is based on the international standard IEC / EN 60034-30-1, which defines classes from IE0 to IE4 for electric motors.

The previous regulation 640/2009 / EC will be superseded by the new regulation (EU) 1781/2019. This new rule defines the minimum requirements for motors and is called MEPS (Minimum Efficiency Performance Standards). For the first time in history, they also include clear rules for inverters as well as IE4 efficiency class requirements for electric motors. Figure 3 shows the evolution of the requirements for energy efficiency classes for various power electric motors.

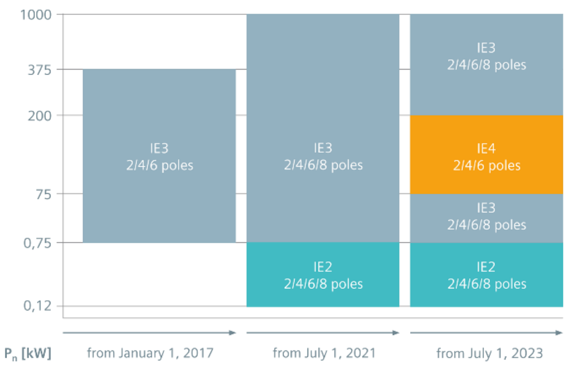

Figure 3 Evolution of energy efficiency requirements.

At the moment, 5 classes of energy efficiency have been identified [7]:

IE1 (standard efficiency),

IE2 (high efficiency),

IE3 (premium efficiency),

IE4 (super-premium efficiency),

IE5 (ultra-premium efficiency).

Figure 4 shows the boundaries of different IE classes of motors of different power [8].

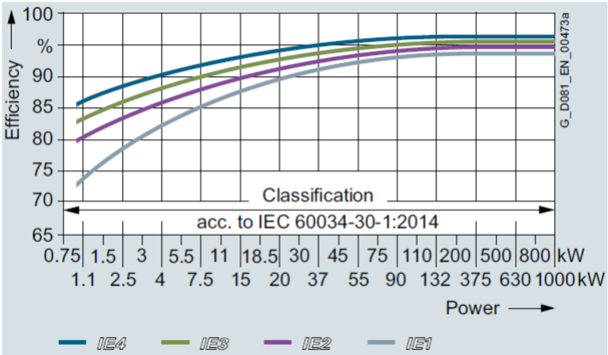

Figure 4 Energy efficiency class boundaries, according to [7].

In the European Union, EU Directives 640/2009 and 2009/125 / EC apply. On the territory of the Russian Federation, as a part of the Eurasian Economic Union, the Technical Regulations of the Eurasian Economic Union "On Requirements for the Energy Efficiency of Consuming Devices" are in force. Within the framework of the indicated documents, on the territory of both unions, the concepts of the minimum energy efficiency of devices are established in accordance with their connection to the network (directly or through a frequency converter), as well as on the generated active power. Figures 5 and 6 show the evolution of requirements for energy efficiency classes for European countries and the Russian Federation.

Figure 5 Evolution of requirements for energy efficiency of motors in the EU.

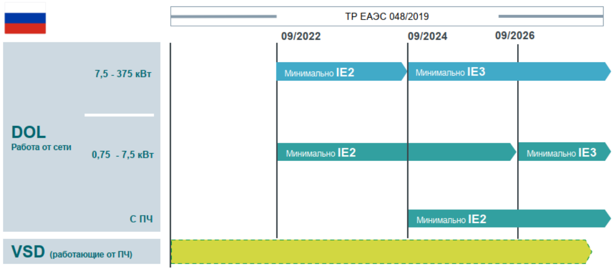

Figure 6 Evolution of requirements for energy efficiency of motors in the Russian Federation.

One of the most promising solutions in the field of energy-efficient drives is the use of synchronous reluctance motors. The synchronous-reluctance drive system has a large power reserve in comparison with a similar asynchronous drive in those overall dimensions. It provides a very high level of efficiency in the full and partial load range compared to traditional asynchronous technology while maintaining high power density and dynamic characteristics. This allows cost savings and energy savings.

The reluctance motor drive system provides maximum (comparable to IE4) energy efficiency at the rated operating point and improves efficiency in the partial load range when compared to asynchronous motors powered by a frequency converter. The disadvantages of an electric drive with a synchronous reluctance motor include the impossibility of operating this motor without a frequency converter since this motor is not self-starting. Due to the operation from a frequency converter, as well as the absence of an excitation winding on the rotor, these motors have a slightly lower power factor compared to their asynchronous analog.

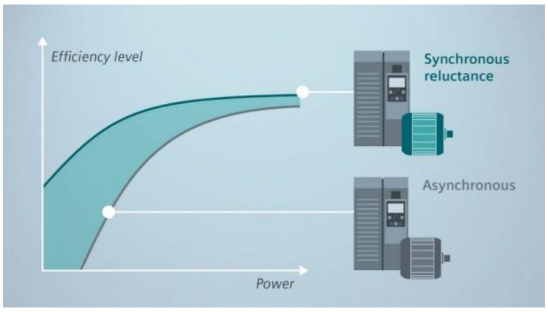

Figure 7 Comparison of asynchronous and synchronous reluctance motor.

4. WAYS TO INCREASE ENERGY EFFICIENCY OF ELECTRIC MOTOR

1. Use of additive technologies. The ability to use a wide range of materials: plastics, ceramics, metal alloys, and even organic / biomaterials puts additive technology at the forefront of modern manufacturing technologies. Currently, there is already experience in the manufacture of coils/windings, electrical insulation elements, stator/rotor magnetic core blocks, permanent magnets, motor housing, structural elements based on the use of new materials and technologies. However, it should be noted the relatively low technological maturity of this technology – for example, magnetic or winding materials have slightly worse physical properties in comparison with existing solutions. However, research and development in this area are progressing rapidly [8].

2. Using a fundamentally new type of insulation. In the process of operation from a frequency converter in the motor, additional losses in the winding caused by PWM modulation occur, however, it is the insulation that is one of the most important components that determine the durability of an electric machine. Siemens, whose motors have a service life of more than 25 years, currently uses DURIGNIT insulation, the main advantages of which are mechanical strength and vibration resistance, chemical resistance, high electrical strength (as well as resistance to current and voltage peaks and surges caused by non-sinusoidal PWM), designed for using F / B. [9]

3. Improving aerodynamic properties to reduce ventilation losses by optimizing the geometry and topology of the rotor.

4. Increasing the accuracy of processing and manufacturing of motor units and parts, as well as increasing the accuracy of the electric drive control system through the implementation of highly sensitive sensors and microcontrollers. Microcontrollers applied to electromechanics must-have characteristics such as a sufficient number of capture modules (CAP), large static RAM, multiple channels of 12-bit ADCs, multiple PWM modules.

5. The use of a motor in conjunction with a frequency converter, which allowed to adjustment of the power factor of the machine, as well as the presence of a frequency converter allows the use of synchronous reluctance motors, the energy efficiency class of which can reach IE5.

6. Use of bearings of a higher class (NSK, SKF), above 6, the design life of which is more than 40,000 hours [10]. An alternative to using traditional bearings could be the introduction of magnetic bearings, which are now only used in high-speed electrical machines. Disadvantages in the magnetic bearing system may lie in the complex control system of the electromagnets in such systems.

Another important parameter characterizing the energy efficiency of an electric motor is the load factor cosφ. The load factor determines the share of active power in the total power supplied to the electric motor from the network.

In this case, only active power is converted into useful power on the shaft, reactive power is needed only to create an electromagnetic field. Reactive power enters the motor and returns to the grid at twice the fundamental frequency 2f, thus creating additional losses in the supply lines. Thus, a system consisting of motors with high-efficiency values but low cosφ values cannot be considered energy efficient. However, in electric drive systems with a frequency converter, this converter can correct the power factor of the drive system.

5. COST OF ENERGY EFFICIENT ELECTRIC MOTORS

When it comes to moving towards more energy-efficient motors, there is no doubt the question of price. The higher price of these motors can be attributed to higher prices for materials such as copper and steel, and since an increase in the proportion of active materials is just one of the ways to increase energy efficiency, this will increase the price of these motors.

Also, the price increase is possible due to high processing costs and more complex materials production technology, such as optimization of the shape of the toothed zone of the magnetic circuit and the design of the windings [11].

It should also be noted that the dimensions of the machine may remain unchanged, however, its energy efficiency will be higher, respectively, the price increase is since when replacing it with a more energy-efficient machine, with greater efficiency, there is no need to increase the space for the motor.

Comparisons were made between two Siemens motors of the SIMOTICS 1LE1501-2CB23-4AB4 range of IE2 energy efficiency class and SIMOTICS 1LE1503-2CB23-4AB4 of IE3 energy efficiency class. The dimensions of these motors were identical, but the weight and moment of inertia of the IE3 class motor were larger. When comparing a SIMOTICS 1LE1502-2CB23-4AB4 motor with an IE1 energy efficiency class with the same IE3 motor, the same data was obtained. The motor weights and moments of inertia varied proportionally, therefore, it can be assumed that the rotor in the IE3 class had a large rotor mass. An increase in the mass of the rotor is carried out by an increase in the amount of steel of which the rotor consists, and, accordingly, the price for this motor also increases [12].

Compared to a motor of a lower energy efficiency class, this motor will be able to pay for itself and save money in the foreseeable future.

6. ENERGY EFFICIENT MOTOR ECONOMIC BENEFITS COMPARISON

Currently, the number of companies that are striving to switch to “green energy” is increasing.

A more efficient motor can save from a few euros to several tens of thousands of euros over its entire service life, depending on its power and usage pattern.

With the help of the SINASAVE service from Siemens, a comparative analysis was carried out of two three-phase asynchronous motors with a power of 55 kW with energy efficiency classes IE1 and IE3, respectively. Figure 8 shows the appearance of the program.

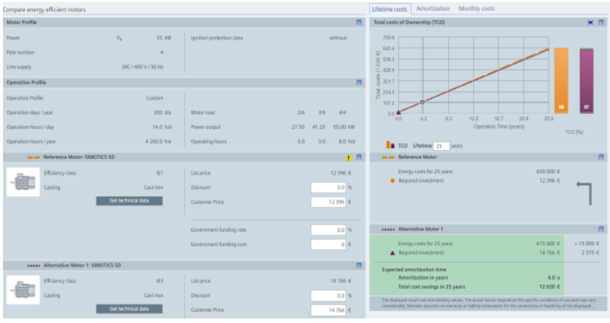

Figure 8 Appearance of SINASAVE.

The customer price for an electric motor with an energy efficiency class IE1 is 12396 euros, and for IE3 it is 14766 euros. The difference is, therefore, € 2,370 at the procurement stage. In the analysis, we assume that the electric motors were running 300 days a year, 14 hours a day. At the same time, the energy consumption of the IE1 motor was 210.3 MW * h / year, for the IE3 motor - 204.6 MW * h / year, that is, the energy-saving potential of 5.7 MW * h / year, which is equivalent to a saving of 3.6 tons/year of carbon dioxide emissions. The service life of Siemens electric motors is 25 years, for this period, according to the program's calculations, it will be possible to save 12,630 euros, which is comparable to the cost of the prime mover and slightly lower than the cost of an alternative motor, but it should be borne in mind that in some countries incentive payments are introduced by the state and discounts to enterprises for the use of resource-saving technologies. When applying this practice in the Russian Federation, we have the opportunity to significantly increase the demand for energy-efficient electric motors, even though these motors practically pay off for the entire service life, but the indicated service life is only approximate since they usually operate longer with proper maintenance.

7. CONCLUSION

The article analyzed the main trends in the field of increasing energy consumption, as well as the main reasons for the growing electricity demand. Particular attention was paid to the relevance of energy efficiency as part of the Energy Strategy of the Russian Federation until 2035, as well as within the framework of international standards. The evolution of both international standards in the field of energy efficiency of electric motors and the standards in force in the territory of the Eurasian Economic Union was presented and studied. Separately, the article discusses the reasons and ways to improve the energy efficiency of currently used electromechanical converters. As an example of the feasibility of switching to such devices, an economic analysis of two identical electric motors with different energy efficiency classes is carried out.

REFERENCES

[1] Report on the functioning of the UES of Russia in 2020

[2] https://vc.ru/u/433123-rusenergonews/134455-energeticheskaya-strategiya-2035

[3] GOST R 54413-2011

[4]https://rep.bntu.by/bitstream/handle/data/36090/Klassy_ehnergoehffektivnosti_ehlektrodvigatelej.pdf?sequence=1&isAllowed=y

[5] D. Dorrell, "A Review of the Methods for Improving the Efficiency of Drive Motors to Meet IE4 Efficiency Standards," in Journal of Power Electronics, Vol. 14, No. 5, pp. 842-851, September 2014.

[6] https://elar.urfu.ru/bitstream/10995/44945/4/urfu1642_d.pdf

[7] International standard IEC TS 60034-30-2 for variable speed motors (https://www.altraliterature.com/-/media/Files/Literature/Brand/bauer-gear-motor/related/brochures/p-7197 -bgm-iec-ts-60034-30-2_en.ashx)

[8] https://elib.spbstu.ru/dl/2/3548.pdf/download/3548.pdf

[9] https://www.szemo.ru/press-tsentr/article/energoeffektivnye-elektrodvigateli/

[10] http://eprivod.com/preimushhestva-i-nedostatki-energosberegayushhix-elektrodvigatelej

[11] http://eprivod.com/preimushhestva-i-nedostatki-energosberegayushhix-elektrodvigatelej

[12] https://mall.industry.siemens.com/

[13] https://www.sinasave.siemens.com/en/efficient simoticsmotors