ANALYSIS OF THE PAYBACK PERIOD OF A MODERNIZED PUMP UNIT WITH INDUCTION ELECTRIC MOTORS OF ADVANCED ENERGY EFFICIENCY CLASSES

**Aim.** The comparative analysis of energy consumption, electricity costs during lifetime cycle and payback period of a pump unit with 90 kW 2-pole induction motors, belonging to various energy efficiency classes, feeding directly from power grid. **Methods.** The examined operating modes aligned with a typical operating cycle of a pump unit with approximately constant flow rate of 75-110 % of the rated flow. The calculations were based on the pump and induction motors nameplate data, which, in their turn, were based on the manufacturers’ experimental data. **Results.** The calculations of energy consumption, electricity costs and payback periods of a pump unit with 90 kW 2-pole induction motors, feeding directly from power grid have been performed in the article. The application of induction motors belonging to IE2, IE3 and IE4 energy efficiency classes has been discussed. **Practical value.** It has been demonstrated, than in case of replacement of an induction motor of energy efficiency class IE2 due to planned retrofit, payback period for an IE4 induction motor is 2.18 years, energy savings within a calculated 20-year operating period are 268 MW·h, which makes €41 110 in money terms. Under the same conditions, the replacement of an induction motor of energy efficiency class IE2 with an induction motor of energy efficiency class IE3 will allow to save 88 MW·h within a calculated operating period, which, expressed in monetary terms, is €13 500 and the payback period is 5.11 years. Thus, the article proves that despite a higher initial price, the choice of an induction motor of energy efficiency class IE4 tends to be more economically advantageous. **Key words:** centrifugal pump, energy efficiency, energy efficiency class, induction motor, throttling control, energy saving, lifetime cycle, payback period.

**Method.** The aim of the article is to analyze the energy consumption of induction electric motors of advanced energy efficiency classes IE2, IE3 and IE4. The calculations were performed to determine the energy efficiency, energy savings, operating period, which, expressed in monetary terms, is €13 500 and the payback period is 5.11 years. Thus, the article proves that despite a higher initial price, the choice of an induction motor of energy efficiency class IE4 tends to be more economically advantageous. References 27, tables 4, figures 1.

**Introduction.** In the world and, in particular, in the European Union, work has long and consistently been carried out to increase the energy efficiency of household appliances, industrial equipment and technological processes. An important part of it is the establishment of energy efficiency classes for electric motors, both powered directly from the electrical network [1], and operating as part of a variable frequency drive (VFD) [2].

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This is due to the fact that according to the research [3], electric motors consume 46% of the electricity generated in the world, and the share of electricity consumption by electric motors in industry is about 70%.

In accordance with the EU regulation [4] of 2009, with the addition of 2014, from January 1, 2017 all electric motors with power from 0.75 to 375 kW, with the exception of those specified in the Standard, must have an energy efficiency class of at least IE3 or IE2, if they are used as part of a VFD. In 2019, the requirements for the energy efficiency of electric motors were updated in the new EU regulation [5], according to which the scope of application of the requirements was expanded and the timing of the introduction of more stringent requirements was determined. So, in [5] it is indicated that from July 1, 2021 2-, 4-, 6-, 8-pole electric motors with power from 0.75 to 1000 kW, with the exception of those specified in the Standard, must have an energy efficiency class of at least IE3. From July 1, 2023 2, 4, 6-pole electric motors from 75 to 200 kW inclusive must have an energy efficiency class of at least IE4 [5]. In the USA, Switzerland, Turkey, Canada, Mexico, South Korea, Singapore, Japan, Saudi Arabia, Brazil, Taiwan and a number of other countries, the use of electric motors with an energy efficiency class of at least IE3 is mandatory [6].

The relevance of the work. According to a European Commission report [3], pumping systems account for almost 22% of the energy consumed by electric motors worldwide. Therefore, studying the possibilities of increasing the energy efficiency of pumping units is an urgent task.

Centrifugal pumps often do not require a wide control range, as well as high starting torque and speed. Therefore, induction electric motors (IMs), operating directly from the electrical network, are widely used in the drives of the mechanisms mentioned above. In this case, the regulation of the performance of the pumps is carried out using valves (throttle control), by means of a controlled change in the characteristics of the hydraulic network. It is known that due to the high costs of frequency converters, not only pumps are characterized by the use of electric motors powered directly from the electrical network. For example, according to the European Commission [1], the share of VFD was about 30% for Germany, and about 20% for Switzerland, according to the study described in [7].

Increasing the energy efficiency of a pumping unit is possible due to changes in the hydraulic network on which the unit operates, the use of VFDs, optimization and distribution of loads (in the case of parallel pumping units), as well as due to the proper selection of unit elements, in particular the use of higher energy efficiency class electric motors [8]. A large number of articles [9-12] are devoted to the issues of reducing the energy consumption of pumping units by using electric motors of different operating principles of higher energy efficiency classes. However, in all of the above-mentioned articles [9-12], a method of regulating pump performance using a VFD is considered. This article discusses the use of electric motors with a higher energy efficiency class, as the most relevant way to improve the energy efficiency of pumps with throttle control.
taking into account year-round and round-the-clock operation, was determined as

\[ E_{d,m.} = 365 \cdot t_s \cdot \sum_{i=1}^{3} \left( P_{i,m} \cdot \frac{t_i}{t_s} \right). \]  

(2)

where \( t_s \) is the total operating time taken equal to 24 h and \( t_i \) is the operating time in each mode.

Electricity cost (€) at tariff \( GT = € 0.188 \) / kWh for industrial consumers in Germany in the second half of 2019 [24] was determined by the formula

\[ C_{i,m} = E_{d,m} \cdot GT. \]  

(3)

The annual cost savings in electricity were calculated as

\[ S_{i,m} = C_{i,m,3} - C_{i,m,2}; S_{2,1} = C_{2,1} - C_{2,2}; S_{2,21} = C_{2,2,1} - C_{2,1}. \]  

(4)

Taking into account that the life cycle of pumping units according to the data [25, 26] is about 15–20 years, for the calculations the service life was assumed \( n = 20 \) years. The electricity costs were calculated over the life cycle of the pumping unit, since the total cost of the life cycle of a pumping unit is mainly the cost of consumed electricity (at least more than 50-60 %) [25, 26]. The net present value (NPV) of the life cycle, determined by the cost of electricity consumed, was calculated as

\[ CLCCE.m = C_{i,m}(1 + (y - p))^{-n}, \]  

(5)

where \( y \) is the interest rate (taken equal to 0.04) and \( p \) is the expected annual inflation (taken equal to 0.02) [25, 26].

The difference in electricity costs during the life cycle of the \( m \)-th IM relative to the existing IM was determined as

\[ \Delta CLCCE.m = CLCCE.m - CLCCE.m. \]  

(6)

In the case of replacing the existing IM of the IE2 energy efficiency class with an IE4 or IE3 IM, the payback period \( T_m \) of the \( m \)-th IM was determined as

\[ T_m = \frac{C_{i,m}}{S_{i,m}}. \]  

(7)

where \( C_{i,m} \) is the initial cost of the considered electric motors, which are given in Table 4 according to [27].

### Results of calculations and their discussion

Table 2 shows the results of calculating the pump operating modes.

| Number of modes (i) | 1   | 2   | 3   |
|---------------------|-----|-----|-----|
| \( Q_i \), %        | 75  | 100 | 110 |
| \( Q_i \), m³/h      | 136.5 | 182 | 200.2 |
| \( H_{mech,i} \), m | 132.6 | 120.6 | 113.9 |
| \( \eta_{mech,i} \), % | 71.3 | 73.8 | 72.7 |
| \( P_{mech,i} \), W | 69176 | 81045 | 85471 |
| \( P_{mech,i} \), % | 76.86 | 90.05 | 94.97 |

Table 3 shows the efficiency values of electric motors according to the catalog for loads of 50 %, 75 % and 100 %, as well as for each operating mode of the pump in accordance with the considered typical operating cycle.

The calculation results using (1)-(7) are shown in Table 4. If an IE2 electric motor in an existing pumping unit is replaced by an IE4 electric motor, the energy savings over the design life are 268 MWh, which is € 41,100 in monetary terms, and the payback period is 2.18 years. In case of replacement with an electric motor of the energy efficiency class IE3, the energy savings during the...
design life is 88 MWh, which is € 13,500 in monetary terms, the payback period is 5.11 years. Thus, for the considered conditions, it is advisable to modernize the pumping unit by replacing the electric motor of the IE2 energy efficiency class. Here, despite the higher cost, the use of an electric motor of the energy efficiency class IE4 will provide a significantly shorter payback period than the use of an electric motor of the class IE3.

**Conclusions.** In the work, calculations of electricity consumption and cost indicators of energy savings for induction electric motors of IE2, IE3, IE4 classes were made, in the case if they are used in a pumping unit operating with flow rate varying within 75-110 % of the nominal one. A comparison was made of the payback periods and electrical energy costs throughout the life cycle for the case of replacing the electric motor in connection with a planned modernization. The payback period for replacing an IE2 motor with an IE4 motor is 2.18 years. Here, the payback period in case of replacement of an electric motor of the energy efficiency class IE2 with an electric motor of the energy efficiency class IE3 is much longer and amounts to 5.11 years. Thus, the choice of an IE4 motor is more cost-effective when upgrading, even though its cost is 30 % higher than that of an IE3 motor. It should be noted that such a technical solution will be especially relevant in light of the choice of an IE4 motor is more cost-effective when compared to a motor of the energy efficiency class IE3 is much longer and amounts to 5.11 years. Thus, for the considered conditions, it is advisable to modernize the pumping unit by replacing the electric motor of the IE2 energy efficiency class. Here, despite the higher cost, the use of an electric motor of the energy efficiency class IE4 will provide a significantly shorter payback period than the use of an electric motor of the class IE3.

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