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“Lost history”  
painting by the artist Valentin Atanasov  
(valopain@yahoo.com)

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36<sup>th</sup> issue

InfoTECH 2022

PROCEEDINGS

IEEE Conference Record #55606



InfoTech-2022 is the 36<sup>th</sup> issue of the traditional scientific conference established in year 1987.

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**InfoTech 2022**  
15-16 September 2022

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## 2022 International Conference on Information Technologies (InfoTech - 2022 – 36th issue), IEEE Conference Rec.# 55606

**15-16 September 2022**

St. St. Constantine and Helena resort BULGARIA

InfoTech-2022 will be organized as a combined format:

1. Preliminary remote access to the abstracts of the accepted articles by using virtual forum on the conference web site from **05 September 2022**
2. Presentation during the conference sessions at **15-16 September 2022**

*The forum is organized in the frame of "Days of the Science of Technical University-Sofia, 2022"*

InfoTech is an international forum for scientists, researchers, industrial experts to share innovations, experience and new research results in the fields of Information Technologies and Information Security; Technologies for System Design and Intelligent Systems; Technological Aspects of e-Governance and Data Protection, etc. The forum is a successor of International Conference on Systems for Automation of Engineering and Research (SAER), established in 1987 and International Workshop on e-Governance and Data Protection (EG&DP), established in 2005

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## 36<sup>th</sup> International Conference on Information Technologies (InfoTech-2022) (IEEE conference, Rec. # 55 606)

15<sup>th</sup> – 16<sup>th</sup> September 2022  
Bulgaria

*The forum is organized in the frame of "Days of the Science of Technical University-Sofia, 2022"*

# PROCEEDINGS

(with the conference program)

Edited by Prof. Radi Romansky, D.Sc.

Sofia, 2022



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- Section [A]: "Information Technologies"
- Section [B]: "Information Security"
- Section [C]: "Networking and Communication Technologies"
- Section [D]: "Intelligent Systems and Applications"
- Section [E]: "Technologies for System Design & Investigation"
- Section [F]: "Technological Aspects of e-Governance and Privacy"

ISSN: 1314-1023

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## Scientific Conference Program

**Thursday, 15<sup>th</sup> September 2022**

**10:00 – 10:05 Official Conference Opening**

**10:05 – 12:00 Virtual Session 1 (Section A: Information Technologies)**

### *Software Technologies and Digital Signal Processing*

- A01 Methods for synthesis of almost perfect and complementary phase manipulated signals with lengths  $N \approx 2m04$**   
*Borislav Bedzhev, Dilyan Dimitrov*  
 Dept. of Communication Networks and Systems, Faculty of Artillery, Air-Defence and Communication-Information Systems, Vasil Levski National Military University, Shumen (Bulgaria)
- A02 A general method for synthesis of constant-amplitude periodic autocorrelation phase manipulated signals**  
*Borislav Bedzhev, Dilyan Dimitrov*  
 Dept. of Communication Networks and Systems, Faculty of Artillery, Air-Defence and Communication-Information Systems, Vasil Levski National Military University, Shumen (Bulgaria)
- A03 Generalized nets representing C based programming constructs**  
*Valeri Petrov Gochev<sup>1</sup>, Nikolay Lyuboslavov Hinov<sup>2</sup>*  
<sup>1</sup> University of Telecommunications and Posts; <sup>2</sup> Technical University of Sofia (Bulgaria)
- Computational Social Science and Social Media*
- A04 Categorization of the requirements of social commerce platforms**  
*Iman Al-Jassasi, Youcef Baghdadli*  
 Faculty of Computer Science, Sultan Qaboos University, Muscat (Sultanate of Oman)
- A05 How robust is the United Kingdom justice system against the advance of deepfake audio and video?**  
*Karl O. Jones, Bethan S. Jones*  
 Liverpool John Moores University (United Kingdom)

### *Bioinformatics and Health Informatics*

- A06 Algorithmization of the process of recognition of biological objects by computed tomography**  
*Teodora Petrova, Zhivo Petrov*  
 Trakia University (Bulgaria)

**14:00 – 16:30 Virtual Session 2 (Section E: Technologies for System Design)**

### *Automation of Design and System Investigation*

- E01 Study of the operation of an automatic robotic line for assembly of electromechanical products using statistics and machine learning**  
*Valentin Tsenev*  
 College of Energy and Electronics, Technical University of Sofia (Bulgaria)
- E02 Improving the tensile strength of solders by stabilizing them with coatings and using statistics**  
*Valentin Tsenev, Nedyalko Peshev, Valentin Yidekov*  
 Technical University of Sofia (Bulgaria)
- E03 Fuzzy production rules on estimations of buck DC-DC power converter parameters**  
*Polya V. Gocheva<sup>1</sup>, Valeri P. Gochev<sup>2</sup>, Nikolay L. Hinov<sup>1</sup>*  
<sup>1</sup> Technical University-Sofia, <sup>2</sup> University of Telecommunications and Posts (Bulgaria)
- E04 Audio restoration of dub plates: Cleaning and digital processing lacquer records from reggae/dancehall culture**  
*Jeremy Blades, Karl O. Jones, Colin Roninson*  
 Liverpool John Moores University (United Kingdom)
- Computer Architecture and Performance Evaluation*
- E05 Omega multistage interconnection network with high-speed forwarding technique handling a double-pattern load**  
*Eleftherios Stergiou, Dimitrios Liarokapis, Spiridoula V. Margariti, Ilias Bobotaris*  
 University of Ioannina (Greece)
- Parallel Systems and Technologies*
- E06 Formalization and investigation of parallel processes dispatching**  
*Radi Romansky*  
 Technical University of Sofia (Bulgaria)



*Power Systems and Energy Efficiency*

- E07 **Energy efficiency improvements in electric drives with centrifugal load**  
*Mihail Dagalovski, Goran Rafajlovski, Krste Najdenkoski*  
Ss. Cyril and Methodius University in Skopje, (North Macedonia)
- E08 **Novel self-adaptive genetic algorithm for solving AC security constrained short-term hydrothermal scheduling**  
*B. Postolov, A. Iliev, D. Dimitrov, A. Causevski and S. Nikolova-Poceva*  
Ss. Cyril and Methodius University in Skopje, (North Macedonia)  
*Renewable Energy, Smart Systems and Energy Efficiency.*
- E09 **Energy management and voltage regulation of grid-connected micro grid using genetic algorithm**  
*Natasha Dimishkovska Krsteski, Atanas Iliev*  
Ss. Cyril and Methodius University in Skopje, (North Macedonia)

**Friday, 16<sup>th</sup> September 2022****10:30 – 11:00 Virtual Session 3 (Section B: Information Security)***Security Policy, Methods and Tools*

- B01 **ISO 27001 framework for securing election infrastructure and machine voting**  
*Veselin Monov* (Switzerland)  
*Cyber-attacks and Security*
- B02 **Applications of simulation modeling method in prevention of jamming attacks**  
*Yoana Ivanova*  
New Bulgarian University (Bulgaria)

**11:00 – 12:00 Virtual Session 4 (Section C: Network Technologies)***Networking – Protocols, Design, Investigation*

- C01 **Investigation of network communications by using statistical processing of monitored data**  
*Radi Romansky*  
Technical University of Sofia (Bulgaria)

*Cloud Computing and Internet of Things*

- C02 **EEG Brain-computer interfaces for Internet of Everything (IoE)**  
*Adelina Georgieva Kremenska, Anna Kostadinova Lekova, Georgi Dimitrov*  
Institute of Robotics, Bulgarian Academy of Science (Bulgaria)
- C03 **Brain-robot communications in the Internet of Things**  
*Svetoslav Emilov Kremenski, Anna Kostadinova Lekova*  
Institute of Robotics, Bulgarian Academy of Science (Bulgaria)

**14:00 – 15:15 Virtual Session 4 (Section D: Intelligent System and Apps)***Intelligent and Agent Systems*

- D01 **Implementation of smart public sector governance systems in the large cities in South-eastern planning region of Bulgaria**  
*Kamen Petrov, Nikolay Tsonkov,*  
University of National and World Economy (Bulgaria)
- D02 **Data pre-processing for ecosystem behaviour analysis**  
*Natalya Rezova, Lev Kazakovtsev, Gazel Shkaberina, Denis Demidko, Andrey Goroshko*  
Reshetnev Siberian State University of Science and Technology (Russian Federation)
- D03 **Development of a classifier for the diagnosis of oncological diseases based on blood protein markers**  
*Liliya Anatolyevna Demidova, Andrey Konstantinovich Gornostaev*  
MIREA – Russian Technological University (Russian Federation)
- D04 **Optimization of hyper parameters with constraints on time and memory for the classification model of the hard drives states**  
*Liliya Anatolyevna Demidova, Anton Vladimirovich Filatov*  
MIREA – Russian Technological University (Russian Federation)  
*Knowledge-Based Applications*
- D05 **Automated access control via license plate recognition using Neocognitron Neural Network**  
*Leon Rothkrantz*  
Department of Intelligent Systems, Faculty of Electrical Engineering, Mathematics and Computer Science, Delft University of Technology (The Netherlands)



**15:15 – 16:15 Virtual Session 6 (Section F: e-Governance & Privacy)**

*E-Government and e-Municipality*

**F01 Analysis of the implementation of smart cities initiatives in Northeast**

**Bulgaria's Districts**

*Nikolay Tsonkov, Kamen Petrov*

University of National and World Economy (Bulgaria)

*E-Learning – Systems and Applications*

**F02 Ontology mapping for personalization in adaptive e-learning**

*Tatyana Ivanova*

TU - Sofia, KEE – Botevgrad (Bulgaria)

**F03 A methodology for mapping educational domain ontologies using top level ontologies**

*Tatyana Ivanova*

TU - Sofia, KEE – Botevgrad (Bulgaria)

*Interoperability in e-Governance*

**F04 A set of registers supporting semantic interoperability in the e-governance's environment**

*Lyubomir Blagoev<sup>1</sup>, Roumen Trifonov<sup>1</sup>, Kamen Spasov<sup>2</sup>*

<sup>1</sup> Technical University - Sofia; <sup>2</sup> Sofia University (Bulgaria)

**16:15 Conference Closing**



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## ENERGY EFFICIENCY IMPROVEMENTS IN ELECTRIC DRIVES WITH CENTRIFUGAL LOAD

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**Abstract:** Electric drives with centrifugal torque characteristic is a typical low efficiency drives. These include fans, pumps, blowers etc. In these electric drives there is great technical and economic potential for significant energy savings. Pumps are the most numerous working machines, therefore the electric drives with pump will be considered in this paper. First, as opportunity to increase energy efficiency will be presented the replacement of existing electric motors in these drives with high efficient motors - HEM. Will be made an analysis how much is savings due to reduced losses in high efficient electric motors. The next, will be given a brief introduction to pump systems and then will be presented the ways in which the operating point of the pump can be regulated. In addition, is presented a calculation for energy savings was made a comparison between conventional ways of regulating the operating point of the pump and regulation of the operating point through variable electric drive speed. It analyzes the electricity consumption of low, medium and high power pumps driven by induction motors that have the ability to regulate the rotation speed through an inverter with U/f regulation.  
**Key words:** Energy Efficiency, Pump Electric Drives, Centrifugal Mechanical Characteristic, High Efficient Electric Motors - HEM, U/f regulation.

### 1. INTRODUCTION

Energy efficiency is the taking of various measures to improve the operation and quality of a particular process and to reduce electricity consumption, and thus to reduce the negative impact on the environment. Thereby, the increased energy efficiency of a certain electric drives must not be at the account of the reduction of production and profitability. In Europe from 2003 to 2012 lasted the Motor Challenge Program - a program supported and supported by the European Commission that aimed to help industrial companies improve the energy efficiency of their electric drives to improve the production process in industry by increasing the quantity and quality and reduce



their impact on the environment, especially with the emission of greenhouse gases into the air [1]. The program puts its emphasis on the drives with working mechanisms that are most common, such as the drives with pumps in the first place which are represented with 33% of all working mechanisms, then compressors, fans, blowers, etc., where there is great technical and economic potential for significant energy savings. The program focused on efforts for application of increased efficiency mechanisms that have the greatest share in improving drive efficiency, followed by the application of energy converters and finally the use of high efficient motors - HEM.

High efficient drives can reduce the cost of maintaining them, improve drive performance, increase productivity and profitability, reduce system losses and thus reduce electricity consumption. If this were to be realized globally, it would result in less need for generation capacity, lower losses in electricity transmission and a cleaner environment. Inefficient use of electricity increases in proportion to the increase in electricity consumption, increased activity in the economy and the use of outdated technology.

In this paper highlights the importance of energy efficiency in electric drives and what it represents. At electric drives, there are two possible ways to increase energy efficiency. One of them is the application of high efficient induction motors [1]. It shows the energy efficiency classes according to a standard published by the International Commission for Electrical Engineering and presents the electricity consumption for all standard powers up to 1MW in induction motors (IM) operating at nominal load 2000, 4000 and 6000 hours per year, respectively according to the energy class to which they belong. In addition, a comparison is made when replacing a standard efficiency motor with a motor with the highest efficiency class to see what the impact of high efficient motors is on improving energy efficiency and energy savings. The second way that is considered and contributes to the improvement of energy efficiency at electric drives involves the application of energy converters. For this purpose, scalar U/f regulation is explained as one of the ways to regulate it. Then an example is presented for improving the energy efficiency of the electric drives with pumps in which the regulation of the operating point is needed. To be clear, a brief introduction to pumping systems and their characteristics is given. Furthermore, it calculates energy savings in operating point regulation by applying inverters with U/f regulation compared to operating point regulation with mechanical control. An analysis was made of seventeen types of centrifugal pumps with low, medium and high power driven by induction motors. At the end, the results are presented, conclusions are drawn and the benefits of the implementation of energy converters are listed.

## 2. REALIZATION OF ENERGY EFFICIENCY IN ELECTRIC DRIVES

The efficiency of an electric drives is determined by the components that assembled that drive, i.e. it is a product of the efficiencies of the individual components that assembled the system. These include first of all the efficiency of the working mechanism, then the efficiency of the control system, the efficiency of the electric

motor, the efficiency of the mechanical transmission system if it exists, etc. High efficient motors and energy converters regulation will be presented below.

### 2.1. Use of high efficient motors (HEM)

In March 2014, the standard IEC 60034-30-1: 2014 was published by the International Commission for Electrical Engineering (IEC), which includes single-phase and three-phase induction cage motors [2]. This standard replaces and extends IEC 60034-30: 2008 which defined three energy efficiency classes for induction cage motors. The new standard from 2014 includes four classes of energy efficiency, includes induction cage motors up to 8 poles, nominal voltage of 50 - 1000 V and output power of 0.12 - 1000 kW.

The following energy efficiency classes are included in IEC 60034-30-1:

- IE1 (Standard Efficiency)
- IE2 (High Efficiency)
- IE3 (Premium Efficiency)
- IE4 (Super Premium Efficiency)

Application field of the standard:

- Power range: 0.12 - 1000 kW
- Voltage range: up to 1 kV
- Frequency: 50Hz / 60Hz
- Number of poles: 2,4,6,8
- Degree of protection: all
- Temperature range: -20°C to + 40°C
- Altitude: up to 4000 m
- Load character: S1

Although IEC standards are applied by many countries in the world, there are differences in their implementation. IEC 60034-30-1: 2014 defines and proposes only the requirements for energy efficiency classes to create a basis for international consistency. It does not specify which motors the energy class must have. This is a specified in national legislation.

The European Union cooperates with the International Electrotechnical Commission and applies many of the standards published by them. Since July, 2011 the European Commission, which is part of the European Union, adopts a regulation according to which induction motors with output power range from 7.5 to 375 kW should not be less efficient than the efficiency specified by the energy class IE2. Since January, 2015 all induction motors with output power range from 7.5 to 375 kW is



adopted not to be with energy class lower than IE3 or IE2 if connected via a power converter, and from January 2017 the same applies as the power range increases, from 0.12 - 1000 kW [2].

The following graph shows all four classes of energy efficiency according to IEC 60034-30-1: 2014, i.e. shows the range in which the efficiency of the engine can move depending on the power, to belong to a certain class of efficiency.

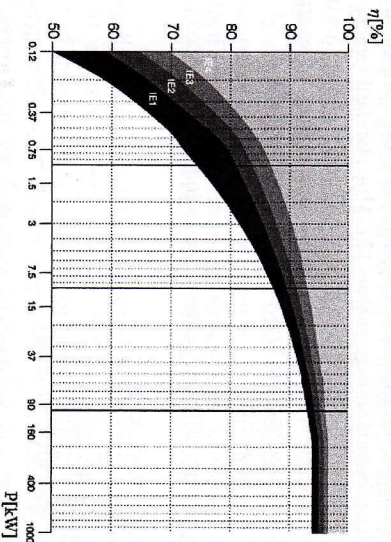


Fig. 1. Energy efficiency classes for four-pole IM, 50 Hz according to IEC 60034-30-1: 2014 [2]

Figure 2 presents a simple analysis of the distribution of costs required in the fifteen-year work life of a three-phase induction motor of the energy class IE2 with a nominal power of 11 kW for 2000, 4000 and 6000 operating hours per year.

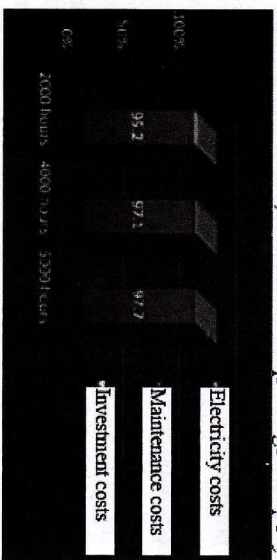


Fig. 2. Analysis of the required costs during 15 years work life for 11kW IM [3]

If induction motors run a large number of hours per year and have a long work life, the capital investment does not have the largest share in the total cost for the entire work life of the motor. As can be seen, the costs related to electricity consumption have the largest share. More than 95% of the total funds required during the 15-year motor life are allocated to the funds required for the consumed electricity. The result of the analysis confirms the fact that even a marginal increase in motor efficiency is crucial

to reduce electricity costs, which in turn contributes to reducing its impact on the environment.

In addition, the corresponding minimum values for energy efficiency will be presented in a table, which according to IEC 60034-30-1: 2014 should satisfy the three-phase induction cage motors with 2, 4, 6 and 8 poles to belong to the corresponding energy class depending on rated power. Table 1 presents the energy efficiencies  $\eta$  [%] for energy classes IE1, IE2, IE3 and IE4 for induction motors with 2 and 4 poles, and Table 2 for 6 and 8 poles.

Depending on the purpose and the drive, the motors can have different number of working hours per year. Table 3 shows the price in euros for electricity consumed in one year if a 2-pole motor operates with a nominal load of 2000, 4000 and 6000 hours per year. The price of electricity is assumed to be 0.12 euros per kWh. The calculations are made for motors with nominal power from 11kW to 1000kW.

$$E = \frac{P[\text{kW}] \cdot t[\text{h}] \cdot \text{electricity price}[\text{€ per kWh}]}{\eta} \quad (1)$$

t - number of working hours per year;  $\eta$  - motor energy efficiency

It can be concluded that with the increase of the energy efficiency, i.e. with the increase of the energy efficiency class of IM, the consumed electricity decreases. In addition, it will be presented how much is the improvement of motor efficiency in percent, and what are the savings in money for the saved electricity depending on the power and the number of working hours per year if a motor with 2 poles of energy class IE1 is replaced with the same such as energy class IE4, and the price for electricity is 0.12 € per kWh.

As can be seen from Table 4, replacing an induction motor of a lower energy class with an induction motor of a higher energy class may increase the efficiency  $k$  of the system from 2.5% to 5%. The savings are most pronounced in motors that have more working hours per year and more power. It is clear that more efficient engines with a higher energy efficiency class are more expensive compared to those with lower energy efficiency, but at the same time bring greater energy savings and have a shorter time to return on capital investment.

Table 1. Energy efficiency classes at IM with 2 and 4 poles according to IEC 60034-30-1: 2014

P	2 poles				4 poles			
	IE1	IE2	IE3	IE4	IE1	IE2	IE3	IE4
0.12	45.0	53.6	60.8	66.5	50.0	59.1	64.8	69.8
0.18	52.8	60.4	65.9	70.8	57.0	64.7	69.9	74.7
0.20	54.6	61.9	67.2	71.9	58.5	65.9	71.1	75.8
0.25	58.2	64.8	69.7	74.3	61.5	68.5	73.5	77.9
0.37	63.9	69.5	73.8	78.1	66.0	72.7	77.3	81.1
0.40	64.9	70.4	74.6	78.9	66.8	73.5	78.0	81.7
0.55	69.0	74.1	77.8	81.5	70.0	77.1	80.8	83.9
0.75	72.1	77.4	80.7	83.5	72.1	79.6	82.5	85.7
1.10	75.0	79.6	82.7	85.2	75.0	81.4	84.1	87.2
1.50	77.2	81.3	84.2	86.5	77.2	82.8	85.3	88.2
2.20	79.7	83.2	85.9	88.0	79.7	84.3	86.7	89.5



3.00	81.5	84.6	87.1	89.1	81.5	85.5	87.7	90.4
4.00	83.1	85.8	88.1	90.0	83.1	86.6	88.6	91.1
5.50	84.7	87.0	89.2	90.9	84.7	87.7	89.6	91.9
7.50	86.0	88.1	90.1	91.7	86.0	88.7	90.4	92.6
11	87.6	89.4	91.2	92.6	87.6	89.8	91.4	93.3
15	88.7	90.3	91.9	93.3	88.7	90.6	92.1	93.9
18.50	89.3	90.9	92.3	93.7	89.3	91.2	92.6	94.2
22	89.9	91.3	92.7	94.0	89.9	91.6	93.0	94.5
30	90.7	92.0	93.3	94.5	90.7	92.3	93.6	94.9
37	91.2	92.5	93.7	94.8	91.2	92.7	93.9	95.2
45	91.7	92.9	94.0	95.0	91.7	93.1	94.2	95.4
55	92.1	93.2	94.3	95.3	92.1	93.5	94.6	95.7
75	92.7	93.8	94.7	95.6	92.7	94.0	95.0	96.1
90	93.0	94.1	95.0	95.8	93.0	94.2	95.2	96.1
110	93.3	94.3	95.2	96.0	93.3	94.5	95.4	96.3
132	93.5	94.6	95.4	96.2	93.5	94.7	95.6	96.4
160	93.8	94.8	95.6	96.3	93.8	94.9	95.8	96.6
200	94.0	95.0	95.8	96.5	94.0	95.1	96.0	96.7
250	94.0	95.0	95.8	96.5	94.0	95.1	96.0	96.7
315	94.0	95.0	95.8	96.5	94.0	95.1	96.0	96.7
355	94.0	95.0	95.8	96.5	94.0	95.1	96.0	96.7
400	94.0	95.0	95.8	96.5	94.0	95.1	96.0	96.7
450	94.0	95.0	95.8	96.5	94.0	95.1	96.0	96.7
1000	94.0	95.0	95.8	96.5	94.0	95.1	96.0	96.7

Table 2. Energy efficiency classes at IM with 6 and 8 poles according to IEC 60034-30-1: 2014

P	6 poles				8 poles			
	IE1	IE2	IE3	IE4	IE1	IE2	IE3	IE4
0.12	38.3	50.6	57.7	64.9	31.0	39.8	50.7	62.3
0.18	45.5	56.6	63.9	70.1	38.0	45.9	58.7	67.2
0.20	47.6	58.2	65.4	71.4	39.7	47.4	60.6	68.4
0.25	52.1	61.6	68.6	74.1	43.4	50.6	64.1	70.8
0.37	59.7	67.6	73.5	78.0	49.7	56.1	69.3	74.3
0.40	61.1	68.8	74.4	78.7	50.9	57.2	70.1	74.9
0.55	65.8	73.1	77.2	80.9	56.1	61.7	73.0	77.0
0.75	70.0	75.9	78.9	82.7	61.2	66.2	75.0	78.4
1.10	72.9	78.1	81.0	84.5	66.5	70.8	77.7	80.8
1.50	75.2	79.8	82.5	85.9	70.2	74.1	79.7	82.6
2.20	77.7	81.8	84.3	87.4	74.2	77.6	81.9	84.5
3.00	79.7	83.3	85.6	88.6	77.0	80.0	83.5	85.9
4.00	81.4	84.6	86.8	89.5	79.2	81.9	84.8	87.1
5.50	83.1	86.0	88.0	90.5	81.4	83.8	85.2	88.3
7.50	84.7	87.2	89.1	91.3	83.1	85.3	87.3	89.3
11	86.4	88.7	90.3	92.3	85.0	86.9	88.6	90.4
15	87.7	89.7	91.2	92.9	86.2	88.0	89.6	91.2
18.50	88.6	90.4	91.7	93.4	86.9	88.6	90.1	91.7
22	89.2	90.9	92.2	93.7	87.4	89.1	90.6	92.1
30	90.2	91.7	92.9	94.2	88.3	89.8	91.3	92.7
37	90.8	92.2	93.3	94.5	88.8	90.3	91.8	93.1
45	91.4	92.7	93.7	94.8	89.2	90.7	92.2	93.4
55	91.9	93.1	94.1	95.1	89.7	91.6	93.1	94.2
75	92.6	93.7	94.6	95.4	90.3	91.6	93.1	94.2
90	92.9	94.0	94.9	95.6	90.7	91.9	93.4	94.4
110	93.3	94.3	95.1	95.8	91.1	92.3	93.7	94.7
132	93.5	94.6	95.4	96.0	91.5	92.6	94.0	94.9
160	93.8	94.8	95.6	96.2	91.9	93.0	94.3	95.1

200	94.0	95.0	95.8	96.3	92.5	93.5	94.6	95.4
250	94.0	95.0	95.8	96.3	92.5	93.5	94.6	95.4
315	94.0	95.0	95.8	96.6	92.5	93.5	94.6	95.4
355	94.0	95.0	95.8	96.6	92.5	93.5	94.6	95.4
400	94.0	95.0	95.8	96.6	92.5	93.5	94.6	95.4
450	94.0	95.0	95.8	96.6	92.5	93.5	94.6	95.4
1000	94.0	95.0	95.8	96.6	92.5	93.5	94.6	95.4

Table 3. Costs for electricity consumed in euros per year depending on the energy class and the number of working hours per year for induction motors with 2 poles

P	2000 h				4000 h				6000 h			
	IE1	IE2	IE3	IE4	IE1	IE2	IE3	IE4	IE1	IE2	IE3	IE4
1.1	3013.7	2953	2894.7	2851	6027.4	5906	5789.5	5701.9	9041.1	8859.1	8684.2	8559.9
1.5	4058.6	3986.7	3917.3	3858.5	8117.2	7973.4	7834.6	7717	12175.9	11960.1	11751.9	11575.6
18.50	4972	4884.5	4810.4	4738.5	9944	9769	9620.8	9477.1	14916	14553.3	14311.2	14215.6
22	5873.2	5783.1	5695.8	5617	11746.4	11563.3	11391.6	11234	17419.6	17049.4	17087.4	16851.1
30	7938.3	7826.1	7717	7619	15876.5	15652.2	15434.1	15238.1	23814.8	23478.3	23151.1	22857.3
37	9736.8	9600	9477.1	9367.1	19473.7	19200	18954.1	18734.2	29210.5	28800	28431.2	28101.3
45	11777.5	11625.4	11489.4	11368.4	23555.1	23250.8	22978.8	22726.8	35337.6	34876.2	34468.1	34105.3
55	14332.2	14163.1	13997.9	13851	28644.5	28256.2	27995.8	27702	43996.7	43489.3	43093.6	42553
75	18417.3	18199.8	18007.4	17828.5	38835	38379.5	38014.8	37655.9	58252.4	57569.3	57022.5	56485.4
90	23225.8	22954.3	22756.8	22547	48851.6	48108.6	47473.7	46957.9	69717.4	68862.3	68210.3	67640.3
110	28257.8	27995.8	27731.1	27500	58591.6	57591.6	56642.2	55800	83967.3	82958.3	82193.3	81250
132	33882.4	33488.4	33207.5	32914	67647.4	66764.7	65915.1	65080.8	101647	100465	99522.6	98794.2
160	40938.2	40526.3	40167.4	39875.4	81012.2	80334.7	79750.8	79215	121519	120502	119513	118523
200	51063.8	50526.3	50104.4	49740.9	102123	101053	100209	99481.9	150131	149474	148791	148239
250	63829.8	63157.9	62630.5	62176.2	127660	125951	124352	122873	191489	189474	187991	186529
315	80425.5	79578.9	78914.4	78342	160851	159158	157829	156684	241277	238737	236743	235026
355	90638.3	89684.2	88935.3	88290.2	181277	179368	177871	176580	271915	269053	266806	264871
400	102128	101053	100209	99481.9	204255	202105	200418	198894	306383	303158	300626	298446
450	114894	113684	112735	111917	229787	227368	225470	223834	344681	341053	338205	335751
1000	255319	252632	250522	248705	510633	505263	501044	497409	765957	757893	751566	746114

Table 4. Money savings in Euros when replacing IM of energy class IE1 with IM of energy class IE4 depending on the number of working hours per year

P [kW]	k [%]	2000 h	4000 h	6000 h
1.1	5	162.7	325.5	488.2
1.5	4.6	200.1	400.2	600.3
18.50	4.4	233.5	466.9	700.4
22	4.1	256.2	512.4	768.5
30	3.8	319.3	638.4	957.7
37	3.6	369.7	739.5	1109.2
45	3.3	409.1	818.3	1227.3
55	3.2	481.2	962.5	1443.7
75	2.9	589	1178.1	1767
90	2.8	678.8	1357.7	2035.5
110	2.7	795.8	1591.6	2387.5
132	2.7	951	1901.9	2852.9
160	2.5	1062.8	2125.3	3188.3
200	2.5	1322.9	2645.8	3968.7
250	2.5	1653.6	3307.3	4960.9
315	2.5	2083.5	4167.2	6250.7
355	2.5	2348.1	4696.3	7044.4
400	2.5	2645.8	5291.6	7937.4
450	2.5	2976.5	5953	8929.6
1000	2.5	6614.4	13229	19843.4



## 2.2. Use of U/f electric motor regulation v.s. valve regulation in a pump system

Fig. 3 shows a diagram for the regulation of water flow through a pump in two ways. The aim is to change the water flow from  $Q_1$  to  $Q_2$ . The first is the conventional way, with mechanical control, i.e. with the use of a control valve where the motor speed does not change. The second way is by regulating the motor speed through an inverter.

### • Valve control

To reduce the flow from  $Q_1$  to  $Q_2$  it is necessary to close properly the regulating valve. The operating point of the pump is moved along the characteristic  $H=f(Q)$  marked in Fig. 1 as  $P_1$ , and passes from the system characteristic  $S_1$  to the system characteristic  $S_2$ . The system characteristic changes from  $S_1$  to  $S_2$  because resistance is added to the system (damping) i.e. the hydraulic losses increase. Increasing the hydraulic losses by closing the valve, increases the effort that the pump has to make to overcome those losses during flow  $Q_2$ . In fact, damping changes the coefficient of resistance of the pipeline and thus changes the position of the operating point of the pump along the curve  $P_1=H=f(Q)$ . The pump effort increases from  $H_1$  to  $H_{2p}$ .

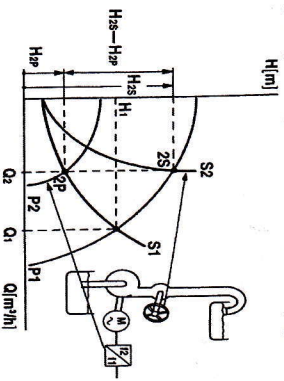


Fig. 3. Centrifugal pump flow regulation [4]

$P_1$  - pump characteristic at rated speed  $n_1$  [ $\text{min}^{-1}$ ]  
 $P_2$  - pump characteristic at reduced speed  $n_2$  [ $\text{min}^{-1}$ ]  
 $S_1$  - system characteristic  
 $S_2$  - system characteristic  
 $Q_1, Q_2$  - pump flow [ $\text{m}^3/\text{h}$ ]  
 $H_{2p}$  - pump effort expressed in [m] at flow  $Q_2$  during valve control  
 $H_{2s}$  - pump effort expressed in [m] at flow  $Q_2$  during motor speed control

### • Motor speed control

To reduce the flow from  $Q_1$  to  $Q_2$ , the operating point of the pump is shifted from characteristic  $P_1$  with a rotational speed  $n_1$  of the  $P_2$  curve with a reduced engine speed  $n_2$ . By reducing the motor speed at flow  $Q_2$ , the effort required for the pump to overcome system losses and the required pressure is reduced from  $H_1$  to  $H_{2p}$ .

Significant energy savings can only be achieved if a wider range of control is required. If the process does not require any regulation and is constant and not dynamic then there can be no question of saving energy by changing the working point. However, a small percentage of processes do not need regulation. In many activities related to human life such as water supply systems, heating, air conditioning, condensate cooling in industrial processes, etc. due to different activities and needs

during different parts of the day, different seasons, different processes, etc. regulated processes are necessary.

### 2.2.1 Result analysis

The purpose of the analysis is to compare the two ways of regulation of flow in an arbitrarily selected pump and to show the saved electricity if the flow is regulated by changing the speed of rotation compared to the conventional way of regulation by using regulating valves. The equations used for the analysis are given below:

Required mechanical power of the pump shaft in both regimes of regulation is:  
 Required pump power for valve control,  $P_{vc}$ :

$$P_v = \frac{Q_m [\text{m}^3/\text{h}] \cdot H_{2s} [\text{m}] \cdot \rho [\text{kg}/\text{dm}^3] \cdot g [\text{m}/\text{s}^2]}{3600 \cdot \eta_1} \quad [\text{KW}] \quad (1)$$

Required pump power for motor speed control,  $P_s$ :

$$P_e = \frac{Q_m [\text{m}^3/\text{h}] \cdot H_{2p} [\text{m}] \cdot \rho [\text{kg}/\text{dm}^3] \cdot g [\text{m}/\text{s}^2]}{3600 \cdot \eta_2} \quad [\text{KW}] \quad (2)$$

Required electrical power in both regimes of regulation is:

Required electrical power for valve control,  $P_{vm}$ :

$$P_{vm} = \frac{P_v}{\eta_m} \quad [\text{KW}] \quad (3)$$

Required electrical power for motor speed control,  $P_{2m}$ :

$$P_{2m} = \frac{P_e}{\eta_m \cdot \eta_{\text{inv}}} \quad [\text{KW}] \quad (4)$$

Energy saving,  $E_s$ :

$$E_s = (P_{vm} - P_{2m}) \cdot t_a \quad [\text{KWh/year}] \quad (5)$$

Saving money per year,  $K_s$ :

$$K_s [\text{saving many per year}] = E_s [\text{KWh/year}] \cdot k [\text{price/KWh}] \quad (6)$$

Where is:

$\rho$  [ $\text{kg}/\text{dm}^3$ ] – liquid density;  $g$  [ $\text{m}/\text{s}^2$ ] – ground acceleration;  $\eta_1$  – pump efficiency at operating point 2S, Fig. 3;  $\eta_2$  – pump efficiency at operating point 2P, Fig. 3;  $\eta_m$  – motor efficiency;  $\eta_{\text{inv}}$  – efficiency of the inverter;  $t_a$  – number of working hours per year

In order to evaluate the efficiency of the two solutions that can regulate the water flow through the pump, it is necessary to make an analysis for a specific pump. For this purpose, a comparison and analysis of the two regulation modes on 17 types of centrifugal single-stage pumps was made, selected from the catalogue of the pump manufacturer Grundfos [5]. The pumps are from the same family and are powered by high efficient induction motors with low, medium and high power. The power range of the motors that will be considered is from 1.5kW to 426kW.

The parameters used in the calculations are taken from the characteristics of each of the pumps from the appropriate catalogues. Table 5 provides data on the pumps used in the analysis, such as the type and serial number of the pump, the rated power of the pump and the induction motor in the drive, nominal flow and effort, efficiency, efficiency class and number of poles.



Table 5. Pumps data [5]

Pump serial number	P <sub>1</sub> [kW]	P <sub>2</sub> [HP]	Q <sub>m</sub> [m <sup>3</sup> /h]	H <sub>1</sub> [m]	η <sub>m</sub> [%]	η <sub>m</sub> [%]	IE	IE	poles
NKE 32-125/1/21 AI-F-A-E-BAOE	1.5	2	19.7	15.7	63.0	88.9	IE4	IE4	2
NKE 32-125/1/40 AI-F-A-E-BAOE	2.2	3	23.4	22.6	67.4	90.1	IE4	IE4	2
NKE 32-160/1/1 A2-E-E-BAOE	3	4	24.8	24.9	61.1	87.1	IE3	IE3	2
NKE 32-160/1/7 A2-E-E-BAOE	5.5	7.5	32.5	36.1	65.4	89.2	IE3	IE3	2
NKE 40-160/1/7 AI-F-A-E-BAOE	7.5	10	43.7	38.6	75.3	90.1	IE2	IE2	2
NKE 40-160/1/7 A2-E-E-BAOE	1.5	1.5	46.0	41.5	75.3	89.4	IE2	IE2	2
NKE 40-250/1/25 A2-E-E-BAOE	18.5	25	60.2	51.9	69.3	90.3	IE2	IE2	2
NKE 150-125-250/2/40 AI-F-A-E-BAOE	18.5	25	234	174	79.8	91.2	IE2	IE2	4
NKE 65-250/28 AS-F2-E-BAOE	37	50	134	68.1	72.7	92.6	IE2	IE2	2
NB 65-250/21 A-F2-A-E-BAOE	45	60	145	77.0	73.6	93.7	IE3	IE3	2
NB 65-250/270 AS-F2-E-BAOE	75	100	161	89.5	75.0	94.6	IE3	IE3	2
NK 80-315/295 AI-F-A-E-BAOE	110	150	244	113.8	75.5	94.3	IE2	IE2	2
NKG 125-80-315/310 AI-F-L-E-BAOE	132	180	263	126.8	75.5	94.6	IE2	IE2	2
NK 80-315/238 AI-F-E-BAOE	160	210	289	143.7	76.8	95.6	IE3	IE3	2
NKG 125-80-400/298 AI-F-E-BAOE	250	340	289	196.9	70.2	95.4	IE2	IE2	2
NKG 200-150-315/1333 GI-F-A-E-BAOE	355	480	965	148.9	83.0	95.5	IE2	IE2	2
IT 400-540/A-F-A-DBUE	450	540	2890	35.0	83.1	94.0	IE2	IE2	4

Table 6 shows the data for the operating point of each of the pumps and the corresponding efficiencies depending on it in both regulation modes, then shows the efficiency of the motor that drives each of the pumps, the number of working hours per year and the price per consumed kWh electric energy. The analysis goes in the direction of changing the operating point of the pump. A flow reduction of 20% of the nominal was made.

Table 6. Pumps working point data

P [kW]	Q <sub>m</sub> [m <sup>3</sup> /h]	H <sub>1</sub> [m]	H <sub>2</sub> [m]	η <sub>m</sub> [%]	η <sub>m</sub> [%]	η <sub>m</sub> [%]	t <sub>a</sub> [h]	E [kWh]	E <sub>1</sub> [kWh]	E <sub>2</sub> [kWh]
1.5	15.8	17.37	8.702	60.4	88.9	62.8	3000	0.12	8	8
2.2	18.7	24.67	12.77	65.6	67.0	90.1	3000	0.12	12	12
3	18.4	27.6	14.43	57.8	61.1	87.1	3000	0.12	14	14
5.5	26	39.6	19.57	64.0	64.8	89.2	3000	0.12	19	19
7.5	35	41.46	21.83	71.0	75.0	90.1	3000	0.12	21	21
11	36.8	44.42	23.56	71.0	76.1	89.4	3000	0.12	23	23
15	48.2	58.4	29.24	68.4	69.1	90.3	3000	0.12	29	29
18.5	203	19.58	9.938	77.0	80.1	91.2	3000	0.12	9	9
37	107	75.1	38.22	71.0	72.6	92.6	3000	0.12	38	38
45	116	87	42.34	72.6	73.3	93.7	3000	0.12	42	42
75	130	98.66	48.78	74.2	74.4	94.6	3000	0.12	48	48
110	159	121.5	51.3	73.3	75.0	94.3	3000	0.12	61	61
152	210	134.8	71.03	73.3	75.4	94.6	3000	0.12	71	71
160	231	152.7	79.37	74.8	76.5	95.6	3000	0.12	79	79
250	231	153.7	107	70.1	70.1	95.4	3000	0.12	107	107
355	773	131.2	69.53	81.6	85.0	95.5	5000	0.12	69	69
450	2310	41.27	18.69	79.5	82.6	94.0	5000	0.12	18	18

When regulating the valve opening, to reduce the flow by 20% from  $Q_1=Q_m$  to  $Q_2=Q_m$  (Fig. 3), it is necessary to close it properly. The operating point of the pump moves along the characteristic  $P_1=H=f(Q)$  and passes from the system characteristic  $S_1$  to the system characteristic  $S_2$ . The speed at which the motor runs is 100% of the nominal. The pump effort increases from  $H_1$  to  $H_2$ .

When regulating the motor speed to reduce the flow by 20% from  $Q_1$  to  $Q_2=Q_m$ , the operating point of the pump is shifted from characteristic  $P_1$  with a rotational speed  $n_1$  of the  $P_2$  curve with a reduced engine speed  $n_2$ . By reducing the rotational speed of the motor at flow  $Q_2$ , the effort required for the pump to overcome system losses and the required pressure is reduced from  $H_1$  to  $H_2$ . The percentage for which the rotation speed should be reduced in order to achieve the required flow depends on the characteristics of the system, i.e. the system characteristic. In other words, the

percentage of speed reduction can't be arbitrary but depends on how much effort the pump has to withstand at reduced flow. For the purposes of this analysis the speed of all analyzed pumps is reduced by 25% of the nominal, which means the motor is running at 75% of the nominal speed and it is assumed that the total effort that the pump has to overcome is not greater than the value  $H_{min}$  of Table 6.

The pump data shown in Table 6, as previously stated, are the data required to perform the calculations, and an explanation of the variables is given below:

$Q_m$  - flow through the pump [m<sup>3</sup>/h];  $H_{1s}$  - pump effort expressed in [m] at  $Q_m$  flow with valve regulation and rated motor speed;  $H_{2p}$  - pump effort expressed in [m] at  $Q_m$  flow with motor speed regulation with inverter at 75% of nominal speed;  $\eta_1$  - pump efficiency at operating point ( $Q_m, H_{1s}$ );  $\eta_2$  - pump efficiency at operating point ( $Q_m, H_{2p}$ );  $\eta_m$  - motor efficiency;  $t_a$  - number of working hours per year.

Table 7 shows the results of the calculation for each of the pumps defined in Table 5 and Table 6, where:  $P_v$  (kW) - required pump power for valve regulation;  $P_e$  (kW) - required pump power for motor speed regulation at 75% of rated speed;  $P_s$  (%) - percentage of power required less when the flow is regulated by motor speed to 75% of the nominal compared to the valve regulation ( $P_s = (P_e/P_v) \times 100$ );  $E_s$  (kWh) - saving electricity by applying an energy converter with U/F regulation at a reduced speed of 25%;  $K_s$  (€) - saving money from the saved electricity

Table 7. Result analysis

P [kW]	P <sub>v</sub> [kW]	P <sub>e</sub> [kW]	P <sub>s</sub> [%]	E <sub>s</sub> [kWh]	K <sub>s</sub> [€]
1.5	1.238	0.597	48.183	2165.100	259.810
2.2	1.916	0.971	50.682	3146.900	377.620
3	2.394	1.184	49.459	4167.900	500.140
5.5	4.384	2.140	48.809	7547.500	905.700
7.5	5.569	2.776	49.845	9300.700	1116.100
11	6.274	3.105	49.845	10653.000	1276.200
15	11.214	5.538	49.561	18792.000	2255.000
18.5	14.066	6.863	48.792	23695.000	2843.400
37	30.841	15.350	49.771	50188.000	6022.600
45	37.009	18.259	49.336	60033.000	7203.900
75	47.103	23.226	49.310	75719.000	9086.200
110	87.482	43.573	49.807	232819.297	27983.315
132	105.237	53.908	51.225	271297.099	32555.651
160	128.503	65.309	50.822	330516.350	39661.962
250	194.672	96.082	49.355	516719.967	62006.396
355	338.680	172.305	50.875	871070.850	104528.502
450	326.773	142.432	43.588	980535.886	117664.270

As can be seen from the results of the table, the regulation of the motor speed by using energy converters as a way to change the operating point of the pump is a much more efficient solution compared to the valve control and brings great savings in electricity if it is the same implements. This is especially true for drives that have variable operating regimes.

### 3. CONCLUSION

The world industry and economy are facing a major energy challenge. Global electricity demand is growing, and pressures to reduce electricity consumption and



reduce the impact on the environment and climate change are growing. If we take into account the fact that as much as 65% -70% of the total electricity consumption in industry is accounted for by electric motors then it is clear that the potential for saving electricity is huge and their role in reducing environmental pollution is crucial.

The biggest part in the improvement of the energy efficiency of an electric drives has the improvement of the efficiency of the working mechanism. In second place are the application of energy converters and then the use of high efficient motors - HEM. The application of energy converters and high efficient motors - HEM are profitable investments, whose return depending on the number of working hours and power, and is from several months to 5 years.

Replacing an standard energy efficiency induction motor (energy class IE1) with a high efficient motor (energy class IE4) can improve the system energy efficiency from 20% for low power motors to a few percent for high power motors. However, the improvement of energy efficiency even by 2% in high power IM contributes to large electricity savings.

To reduce the pump flow by only 20% at a reduced motor speed of 25% of the nominal, the power required by the pump is 50% lower than the power required for valve control. This is a significant reduction in power and a confirmation of the general law which states that the power of a pump depends on the cube of the speed at which it rotates. Reducing the flow of a pump with a valve control is just as inefficient as regulating the car speed only with brakes. Mechanical control consumes electricity unnecessarily. How much is higher the number of working hours and the higher the power of the pump, the energy savings is greater. Knowing that pumps make up 33% of all working mechanisms, it is concluded that by increasing the energy efficiency of pump systems there is a great potential for saving energy and improving their work. The concept of energy efficiency is a very effective way to reduce the emission of carbon dioxide and other harmful substances into the air that contribute to global warming, air pollution and climate change. Global programs aimed at helping industrial companies improve the energy efficiency of their electric drives are needed and are of great importance for raising awareness and assisting in the implementation of energy efficiency.

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