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ANALYSIS OF POTENTIAL OF MORE EFFICIENT ELECTRICITY COST MANAGEMENT CONTROL BY APPLYING MEASURES TO IMPROVE ENERGY EFFICIENCY

ANALIZA POTENCIJALA EFIKASNIJE KONTROLE UPRAVLJANJA TROŠKOVIMA ZA ELEKTRIČNU ENERGIJU PRIMJENOM MJERA ZA POBOLJŠANJE ENERGIJSKE EFIKASNOSTI

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Abstract: The electricity supplier, having direct contact with end consumers, has significant potential for contributing to the achievement of country's strategic goals related to increasing the share of electricity production from renewable energy sources and promoting efficient use of electricity. This paper presents the concept of conducted analyses of energy efficiency at the customers of JP Elektroprivreda BH d.d. Sarajevo for the purpose of identifying consumers where it would be useful to apply some of the energy efficiency measures and/or peak load management, all for reducing electricity costs. The results of the analysis are presented in the paper. Special attention is given to the techno-economic analysis of the application of measures used to improve the energy efficiency. The results of the analyses show that the shortest payback period is achievable by adequate waste heat recovery in compressors and refrigeration systems, reactive power compensation, control of motor drives of pumps and fans, and the replacement of motors with a higher efficiency class.

Keywords: energy efficiency, electricity supplier, demand side management, electricity consumers, electric motor drives

Sažetak: Snabdjevač električnom energijom ostvarujući neposredni kontakt sa krajnjim potrošačima posjeduje značajan potencijal za doprinos ostvarenju strateških ciljeva jedne zemlje koji se odnose na povećanje udjela proizvodnje električne energije iz obnovljivih izvora energije te promoviranje efikasnog korištenja električne energije. U radu se daje koncept provedenih analiza efikasnosti utroška električne energije kod kupaca JP Elektroprivreda BiH d.d. Sarajevo u svrhu identifikacije potrošača kod kojih bi bilo korisno primijeniti neku od mjera energijske efikasnosti i/ili upravljanja vršnim opterećenjem a sve u svrhu smanjenja troškova za električnu energiju. Predstavljaju se rezultati analiza efikasnosti utroška električne energije provedenih kod krajnjih kupaca JP Elektroprivreda BiH d.d. –Sarajevo. Poseban osvrt daje se na tehno-ekonomsku analizu primjene mjera za poboljšanje efikasnosti utroška električne energije. Rezultati analiza pokazuju da je najkraće razdoblje povrata investicije moguće postići rekuperacijom otpadne topline u kompresorima i rashladnim sistemima, kompenzacijom reaktivne snage, upravljanjem motornih pogona pumpi i ventilatora te zamjenom motora sa motorima veće klase efikasnosti.

Ključne riječi: energijska efikasnost, snabdjevač električnom energijom, upravljanje potrošnjom električne energije, potrošači električne energije, elektromotorni pogoni

INTRODUCTION

Increasing the energy efficiency together with the use of renewable energy sources represents the backbone of the energy transition that, facing global energy challenges, seeking to ensure a secure, sustainable, market-based power system, is being implemented in the European Union [1]. The Law on Energy Efficiency in the Federation of Bosnia and Herzegovina [2] regulates, inter alia, energy efficiency in final

consumption whose increase is an activity of general interest, measures to improve energy efficiency including energy services and energy audits, public sector obligations, obligations of large consumers as well as the rights and obligations of end consumers. The obligation of large consumers is to establish an energy management system and to adopt a program to improve energy efficiency for a period of three years. The energy source distributor, distribution system operator and electricity supplier are obliged to perform activities within their competence in a way that does not interfere with the supply of energy services and other measures for energy efficiency improvement and does not interfere with the development of the market of energy services and other measures for energy efficiency improvement.

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Energy audit, in terms of industrial plants, represents a documented procedure for gaining appropriate knowledge about the existing energy consumption of the technological process and/or industrial plant in order to determine the cost-effectiveness of measures for energy efficiency improvement, as well as to report on collected information and proposed measures. Energy audit consists of data collection, measurement of final energy consumption, calculation of energy characteristics, and assessment of energy efficiency and identification of measures for energy savings.

There are several widely applicable energy efficiency measures in industry such as motor replacement with a more efficient one, regulation of electric motor drives, reactive power compensation, measures related to compressed air systems and/or refrigeration systems etc. The issue of energy management in industrial plants has been addressed in [3]. A review of methods for energy-efficiency improvement in induction machines is given in [4]. Energy efficiency measures that can be applied in compressed air systems are reducing compressor pressure, lowering air inlet temperature, adequate storage capacity, recovering residual heat from the air compressor and reducing leakage, that can produce energy savings between 20% and 60% [5]. Energy savings in compressed air systems has been analysed in [6]-[8]. Reactive power compensation of electric motor drives is addressed in [9]-[10].

Striving to follow the guidelines and strategy of the European Union in the field of energy efficiency as well as the legislation of Bosnia and Herzegovina, while insisting on maintaining a competitive position in the retail electricity market, JP Elektroprivreda BH d.d. - Sarajevo has started activities to promote and advise end customers on the benefits and possibilities of implementing measures to improve energy efficiency.

The paper presents the structure of the conducted reviews of the efficiency of electricity consumption in specific case studies. In Chapter 1 the methodology of conducting energy audit is given. Chapter 2 gives the results of the energy audits and finally Chapter 3 presents the concluding considerations.

1. IMPLEMENTATION OF ENERGY AUDIT

1.1. Methodology

In order to successfully conduct an energy audit (fulfilment of defined goals), the auditor should have an overview of the overall consumption of the client. Based on that, potential metering points are determined and measurements are taken. In accordance with the already defined goals the analysis of the metering results is performed and appropriate energy efficiency improvement measures (potential savings / investments) are proposed.

In general, the energy audit is conducted in three basic phases:

- Phase of data collection on electricity consumption: For the sake of simplicity, the client preliminarily fills in a general energy audit questionnaire (list of major consumers, business organization, specifics of general consumers and previously implemented measures for energy efficiency improvement). Then, working meetings are organized during which detailed data related to the electricity consumption of important consumers is collected (role in the process, methods of work and other specifics related to consumers). Consumers are classified into three basic categories (sorted by priority of the analysis):
 - o consumers with continuous operation (ranked by rated power),
 - o consumers or groups of consumers with higher nominal power that conduct occasional work during the period of validity of the higher daily tariff and whose work can be moved to the period of validity of the lower daily tariff,
 - o other specific consumers.

The potential effects of implementation of measures for energy efficiency improvement are analysed for each consumer (reactive power compensation, replacement and control of electric motor drives, lighting, waste heat recovery, peak load management through work organization measures, determining the share in total consumption, etc.), on the basis of which a set of measuring points is defined.

- Measurement phase: Measuring equipment is installed at each defined measuring point. Measurement time (resolution and duration) is defined depending on the measurement goal. Measuring equipment consists of:
 - o measuring devices (with appropriate memory capacity, configuration/data access software) with the A/S power measurement accuracy class (IEC 61000-4-30) and a basic sampling resolution of 2 ms per measuring channel,
 - o voltage terminals (pliers),
 - o current-carrying (Rogowski) coils,
 - o other ancillary equipment.

Depending on the measurement objectives (transient processes, continuous consumption), the measurement resolution is selected (1 s or 1 min respectively) where the device aggregates the data to the level of the selected resolution in accordance with the appropriate standards (IEEE 1459). The total duration of the measurement is limited by the memory capacity and format (usually in practice maximum duration is 3 weeks). During the site visits, a thermal inspection of key points is performed. An example of connecting measuring device is shown in Figure 1. An example of thermal inspection is given in Figure 2.



Figure 1: An example of connecting measuring device



Figure 2: Result of thermal inspection

- Analysis of measurement results:
In accordance with the defined measurement objectives, a unified analysis of measurement results is performed for each measurement. Taking into account data resolution, the data is stored in an OpenSource DataBase and the analysis (graphically and statistically) is performed in a purpose-built programming environment (since constant changes and adjustments are required depending on the type of analysis).

Data on electricity consumption is aggregated into 15-min intervals (fixed 15-min intervals per day) for easier presentation and better understanding, except in the case of transient analysis (starting currents, voltage conditions).

The analysis places special emphasis on potential places for savings (assessment of annual financial savings). In the case of typical projects whose values are roughly known on the market (reactive power compensation, higher efficiency motors procurement, application of frequency regulators (variable-frequency drive, VFD)), the return on investment (ROI) is calculated on the basis of which the client can make an assessment of further action.

2. EXAMPLES OF RESULTS OF ENERGY AUDITS

Industrial electricity consumers can be divided into two basic categories:

- General industrial consumers (transport drives, fans, pumps, compressors, etc.);
- Consumers specific for the appropriate type of industry (refrigeration systems, cooking ovens, cutters, packers, etc.).

Given that specific consumers in the relevant industries (food production, cement, etc.) require specialist knowledge, it is not possible to make appropriate changes (improvements) in these specific processes without adequate support from the manufacturers of the equipment. For this reason, we first analyse energy efficiency of general consumers where standardized measures, that can achieve appropriate savings, already exist.

2.1. Reactive power compensation

The presence of inductive elements in the network (transformers, long cables, large asynchronous motors, etc.) results in increased reactive (inductive, lag) power consumption. Adequate compensation of reactive power contributes to:

- Improvement of a power factor (reduction of costs of excessive takeover of reactive energy);
- Reduction of active power losses and unloading the network and equipment;
- Elimination of higher order harmonics;
- Stability and quality of voltage conditions.

Depending on the place of installation at the plant, the reactive power compensation can be:

- Direct (compensation of individual consumers, long cable feeders, etc.);
- Group (compensation of a group of consumers on the same feeder, busbars, etc.);
- Central (compensation at the point of connection of consumers to the distribution network);
- Combined (combination of any of the already mentioned types).

Direct compensation at a low voltage side is the best type of compensation since it eliminates reactive power flows in the local network. Considering the number of consumers in the local network and the way of consumption (occasional work, etc.), group compensation gives a better effects compared to direct (less investment since a smaller number of capacitor units - smaller total capacity is needed). If the group compensation does not achieve the appropriate effect (elimination of the costs of excessive takeover of reactive energy), it is necessary to perform central compensation. The combination of central, group and direct compensation should be applied when it is possible to achieve savings by reducing active energy losses through group (direct) compensation.

According to the mode of operation of the reactive power compensation system (ordered by price and possible

control accuracy), the reactive compensation can be:

- Fixed (direct connection of capacitors): It is used to compensate the known reactive-inductive component of the system (e.g. compensation of the inductive component of the transformer/motor impedance, etc.).
- Automatic (switching of capacitor units via contactor is controlled by the controller): This type of compensation is used where the level of reactive power is variable, and the requirements for precision and target compensation are not strict because the number of on/off operation cycles of the contactor per time unit is limited.
- Automatic (Static VAR compensator (SVC)/ Static Synchronous Compensation (STATCOM) - switching of capacitor units via thyristor switches): This type of compensation can meet strict design requirements (regulation of voltage on the transmission network in tight boundaries, at the connection points of large and rapidly changing loads, etc.).

Fixed, direct and automatic group compensation (with one fixed degree) meet the requirements for reactive energy compensation of analysed consumers. In the example of the pump electric drive whose nominal parameters are given in Table I, the measurement showed that the engine, when running, runs at 95% of rated power, with a total operating time of 45% of recording time (approximately 29 days in 6th and 7th month). By direct compensation of the motor (75 kVAr) it is possible to achieve savings for 6.6 MWh. The return on the investment, in this case, is up to 1.5 years. Such savings are primarily possible due to the large length of the connecting cable line (feeder) (for feeder lengths below 50 m, the return on investment would be longer than 5.5 years).

Table I: Nominal parameters of pump motor and cable line

Motor and feeder parameters	
Nominal power (kW)	200
Nominal efficiency	0.95
Nominal voltage	400
Measured reactive power (kVAr)	95
Measured active power (kW)	200
Feeder active resistance (mΩ/m)	0.18
Feeder length (m)	180

The analysis of the cost of reactive power compensation at 6 kV busbar, where adequate group reactive power compensation within the consumer local network at 0.4 kV has already been implemented but the cost due to excessive takeover of reactive energy at the metering point has not been eliminated (average power factor of monthly calculations is 0.67), was also performed. During such analysis, it is necessary to estimate the total compensation capacity, number and type of stages, and examine whether anti-resonant inductors (choke reactors) of appropriate attenuation and capacitor units of appropriate voltage level are needed accordingly. The minimum

compensation capacity that meets the cost elimination requirement is estimated at 450 kVAr. The impact of higher compensation capacity is shown in Table II.

Table II: Example of reactive power compensation at 6 kV busbar: The impact of total compensation capacity on power factor

Total comp capacity (kVAr)	Average measured power factor	Min measured power factor	% time $pf \geq 0.95$	% time $pf \geq 0.99$
450	0.990	0.96	92	66
500	0.995	0.98	97	80
500	0.998	0.99	99	90

For the detailed analysis (number of degrees and type of compensation), the option of a total capacity of 500 kVAr was considered. Minimum, maximum and average reactive power compensation for amounts of active power realized during period of measurement is shown in Figure 3. A correction of power factor due to application of the stated compensation is given in Figure 4.

Compensation of 500 kVAr can be realized with one fixed stage of 100 kVAr and 400 kVAr in 4 stages of the following scheme: 1, 1, 2, 4. At the same voltage level, it is recommended to compensate the distribution transformer (since the average transformer load is 11%) in a fixed amount of at least 50 kVAr (depending on the rest of the network and the distributor's priorities). After applying such compensation, the power factor would be visibly improved. For the level of higher loads, that rarely occur (load greater than 850 kW occurs only 5% of the time), the minimum amount of power factor is 0.945. The payback period of such investment is between 1.3 and 3.5 years (in case the presence of higher harmonics of current and voltage of the appropriate amount is determined, which requires the installation of anti-resonant chokes).

2.2. Motor drives: replacement and control

Motor drives (AC) represent electricity consumers with great potential savings, due to:

- Possible oversizing (design requirements do not correspond to the current capacity of use, as shown in Figure 5);
- Low efficiency class (for older motors whose nominal efficiency class is below the standard defined efficiency classes: IE1, IE2, etc.);
- Age (working conditions, overheating, rewinding, adjustments, etc.);
- Possibility or need for control (reduction of speed, flow, etc.).

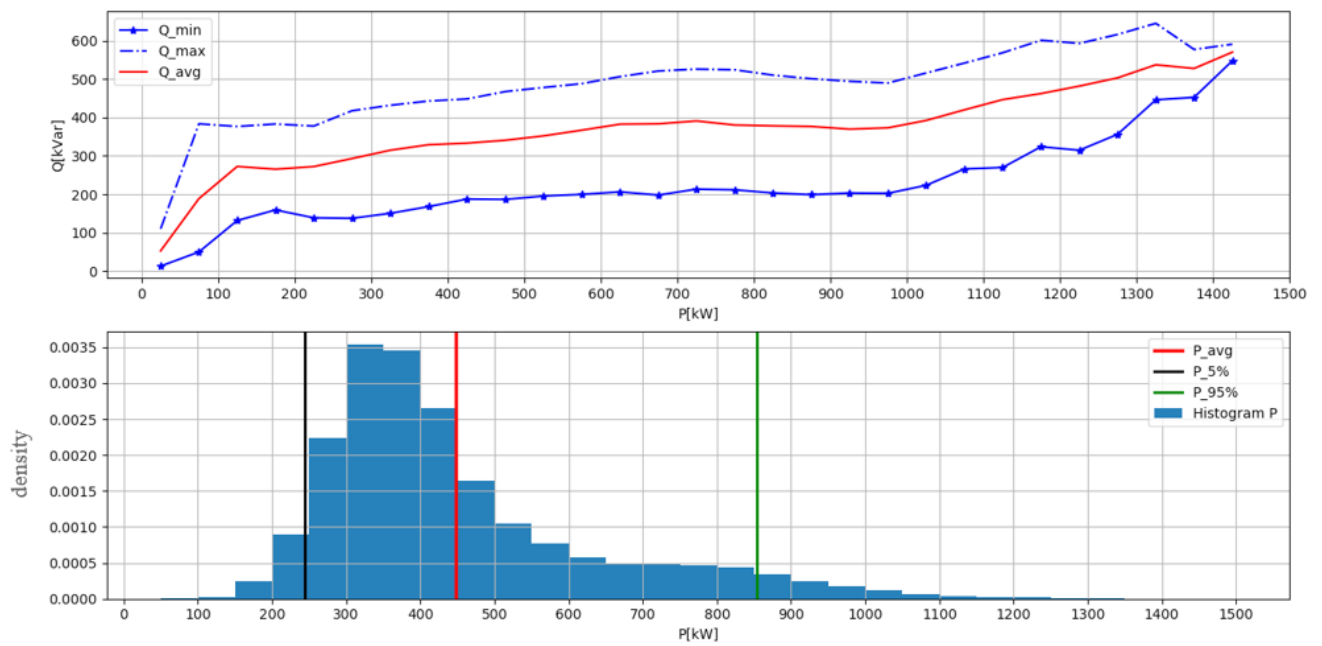


Figure 3: Example of reactive power compensation at 6 kV busbar: Level of needed compensation at load

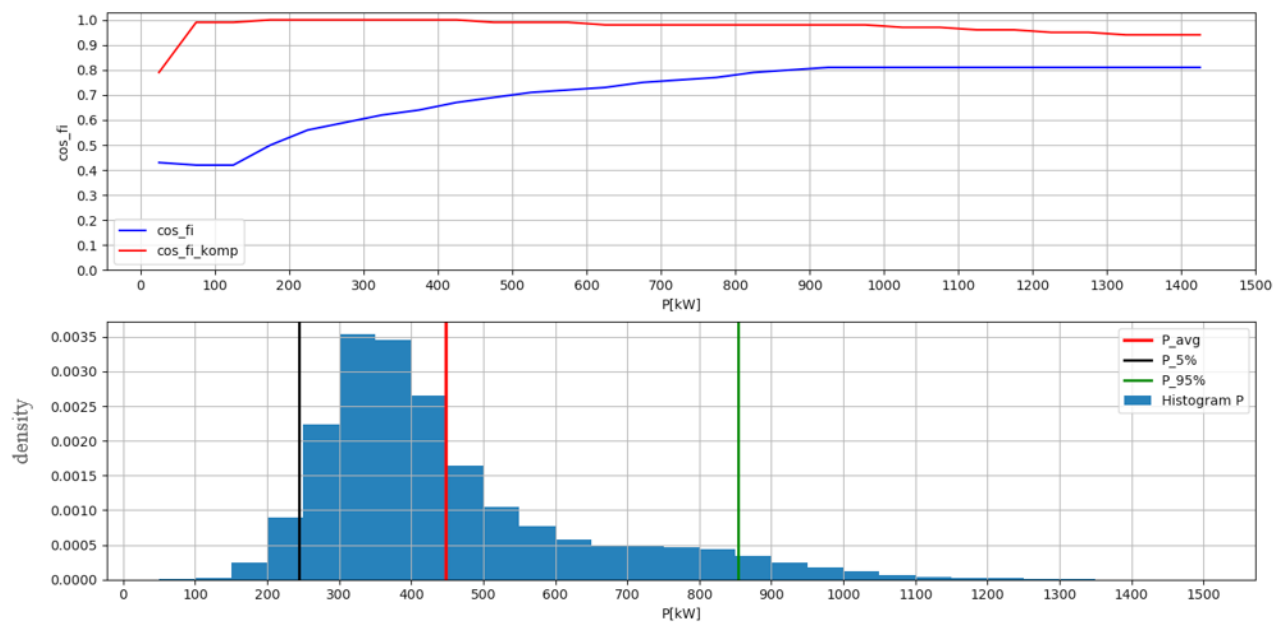


Figure 4: Example of reactive power compensation at 6 kV busbar: Power factor correction at load

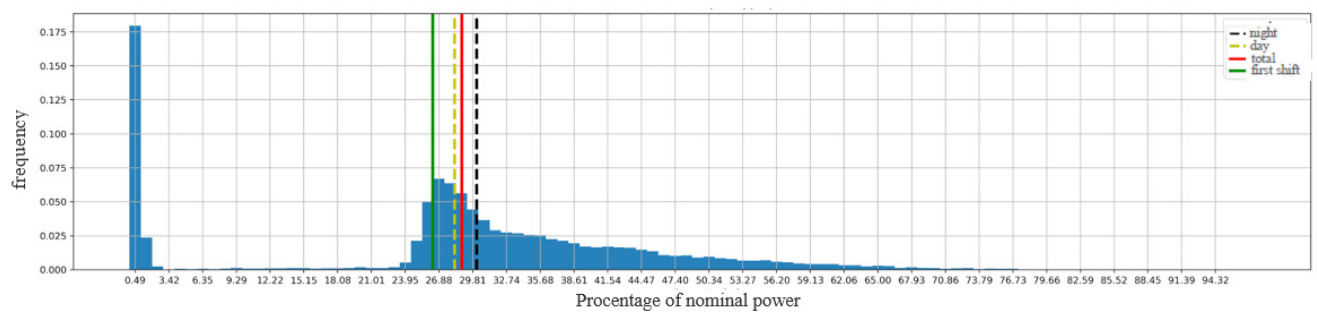


Figure 5: Measured percentage of load of motor drive of the conveyor belt

2.2.1. AC motors replacement

Analysis of the motor drive of the conveyor belt with two asynchronous motors adapted to operate at 500 V, nominal data given in Table III, found that the motor load greater than 70% appears only 0.7% of operating time. In 9% of operating time load is greater than 50%, while the average load is around 30% including time when the conveyor is not working.

Table III: Nominal motor parameters of the conveyor belt

P (kW)	Speed (rot/min)	Year of production	Nominal power factor
75	1460	1981	0.86

Replacing this pair of motors with lower power motors (example 55 kW) with higher efficiency class (IE3/IE4) would reduce power consumption by a minimum of 15% (do not taking into account the financial effects of a smaller share in monthly peak load). The payback period of such investment is less than 3 years.

2.2.2. Control of AC motors

Significant savings can be achieved if there is an appropriate need/possibility to control motor drives (reducing speed, air flow, water, etc.) without disturbing the rest of the process. Control of motor drives can be achieved by installing VFD. Appropriate savings can be made by manually controlling the speed reduction in several steps (e.g. steps of 150 rpm).

For example, in a conveyor belt, where design requirements are such that the conveyor belt is dimensioned to transport about 4 times more material compared to the current working capacity, there is additional possibility for savings through the control of the electric motor drive. The energy savings in this case are directly proportional to

the reduction of the rotational speed (reduced by the energy losses in the inverter). The payback time of such investment depends directly on the selected speed but with a minimum speed reduction of 10% the payback time for such investment is around 3 years.

In general, significant savings can be achieved if proper control can be achieved on motor drives of pumps or fans. The reduction of the flow is directly proportional to the reduction of speed, and reduction of consumption is proportional to the third degree of the same coefficient, as it is shown in relations (1) and (2):

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \quad (1)$$

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2} \right)^3 \quad (2)$$

where:

Q_1 represents flow at rotational speed N_1 ,

Q_2 represents flow at rotational speed N_2 ,

P_1 represents power at rotational speed N_1 ,

P_2 represents power at rotational speed N_2 .

If it is possible to reduce the speed so that the pump operating point is close to the optimal pump efficiency/fan operating point (best efficiency point, BEP), additional savings can be achieved based on achieving better pump operating conditions, of the order of 10%. By adequately choosing to reduce the speed of rotation, it is possible to achieve such a cumulative effect. In the example of a pump with a nominal power of 200 kW, by reducing the rotational speed by 10%, it is possible to achieve energy savings of about 30% (including VFD losses of 5%). The return on such investment (procurement and installation of VFD) in this case would be up to 1.5 years. The time load diagram of analysed pump motor and an example of adequate dimensioning of the motor drive of the pump are shown in Figure 6 and Figure 7, respectively.

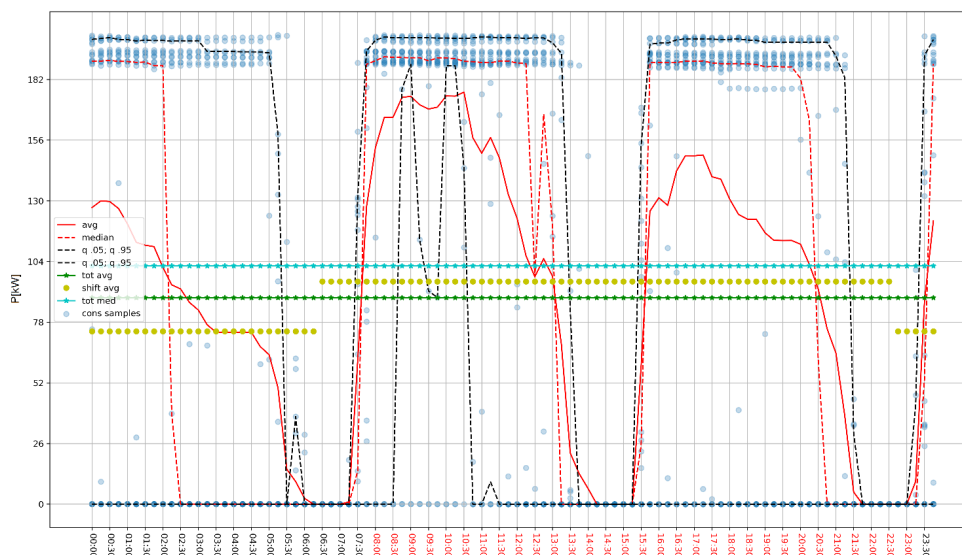


Figure 6: Load diagram of pump motor

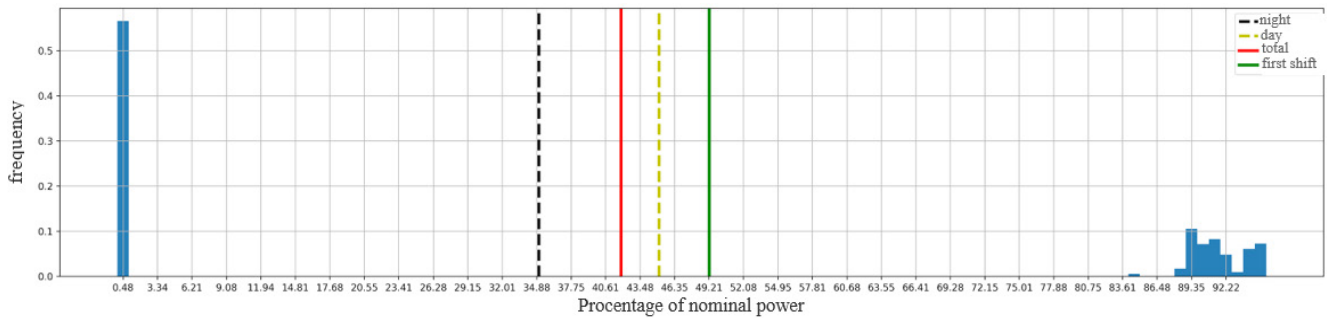


Figure 7: Percentage of nominal motor load (adequate load sizing)

2.3. Compressors (compressor plants)

During the life of compressor, 75% of the total costs are accounted as electricity costs [11], which emphasises importance of adequate selection of compressors (plants), distribution system (with loss minimization), and air consumers. Adequate selection of the compressor plant (power, efficiency and mode of operation) significantly affects the electricity consumption since the under loaded compressor consumes about 2 times more electricity in unloaded mode [12]. If the needs for air during operation vary significantly, it is more efficient to have two or more compressors in joint operation selected so that the base compressor load is adequate to operate in conditions of lower air needs, while current needs for additional air is covered by lower power compressors.

In order to make an accurate assessment of the efficiency of the compressor plant, it is necessary to measure air consumption and electricity consumption simultaneously. Considering that JP Elektroprivreda BH d.d. - Sarajevo currently does not have instruments to measure airflow; the above analysis has not been performed so far.

When it comes to compressor plants, it is important to keep in mind that 80% of electricity can be reused in the form of heat energy through appropriate exchange units [13]. Based on the measurement of electricity consump-

tion, it is possible to give estimate of the compressor load, estimate of the level of leakage in the system, and the amount of waste thermal energy that can be reused. If the available thermal energy from the compressor can be adequately used and at the same time it is possible to achieve equivalent energy savings (preheating/heating water in electric boilers, etc.), where the payback period is up to 1.5 years.

Significant savings in terms of air leakage reduction can be achieved by an adequate inspection of air distribution system, including end consumers (savings of 1 kW would mean savings of the order of 1500 BAM/year). Air leakage is estimated based on the duration of the compressor load/unload cycle in periods when there is no operating air consumption. If the relative duration of the load cycle is greater than 10%, professional inspection of air leaks (ultrasonic leak meters) is recommended, as well as other measures such as the installation of solenoid valves, replacement of inadequate air consumers, etc.

With greater variability in air demand, non-compliant mode compressors may have a higher number of starts per time unit compared to engine catalogue data, which contributes to overheating that significantly reduces engine life. Compressor, whose motor is nominally provided for 4 starts per hour, is activated up to 11 times per hour during operation (useful air consumption), that is shown in Figure 8.

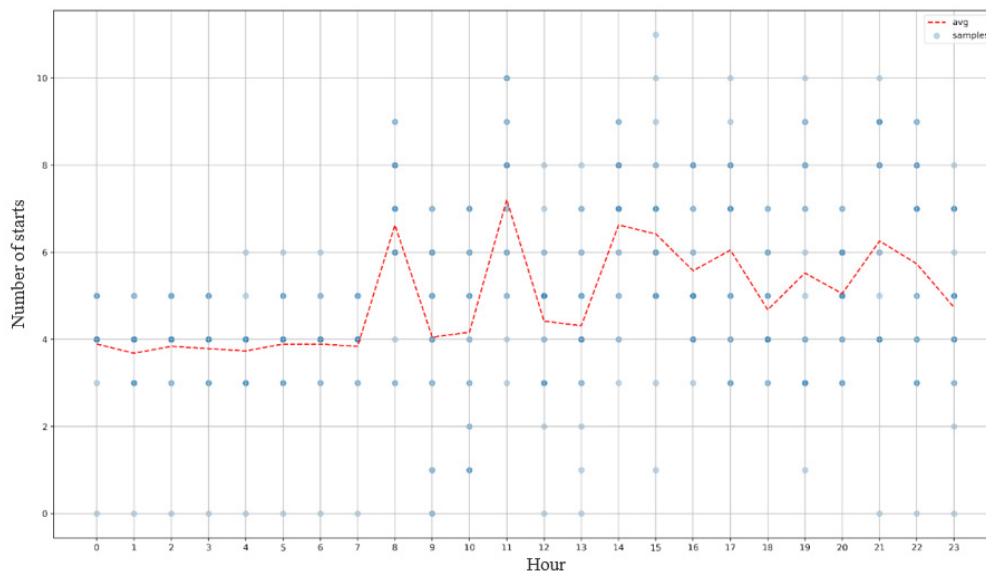


Figure 8: Number of compressor motor starts/hour

Thermal inspection of the engine, taking into account the insulation class (B) on the basis of which the surface temperature of engine can go up to 100°C, determined that it is not close to overheating in the observed period, which is shown in Figure 9.

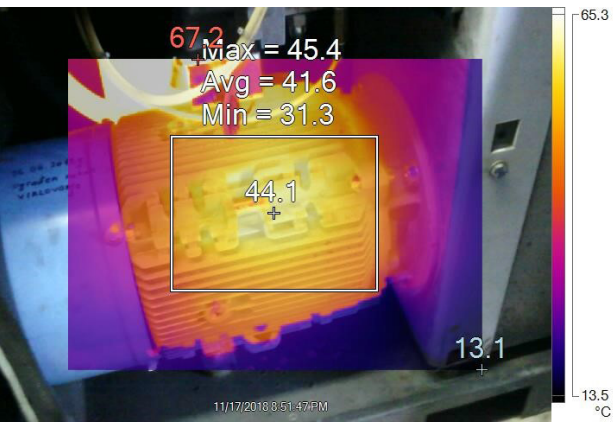


Figure 9: Thermal vision of compressor motor

2.4. Specific consumers

In the group of specific consumers (consumers that are frequent in certain industries), in addition to the use of appropriate options for alternative energy sources (gas, etc.), the emphasis is on the possibility of using waste energy (most often thermal energy).

2.4.1. Refrigeration systems

Refrigeration systems are often used in food industries (production, food storage, etc.). The concept of operation of the refrigeration system is such that the excess heat energy from the refrigeration chambers, within which the temperature is regulated to the set temperature, is transferred to the condenser via evaporator and refrigerant

(R404, R32, etc.). Refrigerant outlet temperatures are significantly higher than the air temperature where the condenser unit is located. The operational values of the Coefficient of Performance (COP) of the analysed cooling systems were 2.3-2.9, while the measurements were performed in the winter period (air temperature around 5°C). The total heat energy released is equal to the amount of electricity consumed multiplied by COP factor.

These systems usually involve the parallel operation of several compressor units, since there are significant differences in the operating modes during the summer and winter period, and it is necessary to take it into account during the analysis. The analysis and its quality depends on the availability of accurate catalogue data. Catalogue data from reputable manufacturers of the equipment is usually presented via the software (catalogue selection of system components given in Figure 10 shows the interface of one such software).

The analysis results in estimate of the minimum heat energy (temperature at the outlet of the compressor) that is released on the condenser, based on the measurement of electricity consumption.

Since the temperatures of the refrigerant at the outlet of the compressor are around 70°C (average of the measured systems), this heat energy can be reused through appropriate heat exchangers during the rest of the production process where the heat is needed in the form of hot water, space heating, etc. Based on previous experiences and assumptions that the 80% of this energy can be reused, the equivalent of usable thermal energy is twice as high in relation to electricity consumption. The return on such investments depends on whether this amount of heat is needed in the process, but even partial utilization (10%) can mean that the return on investment is around 1 year.

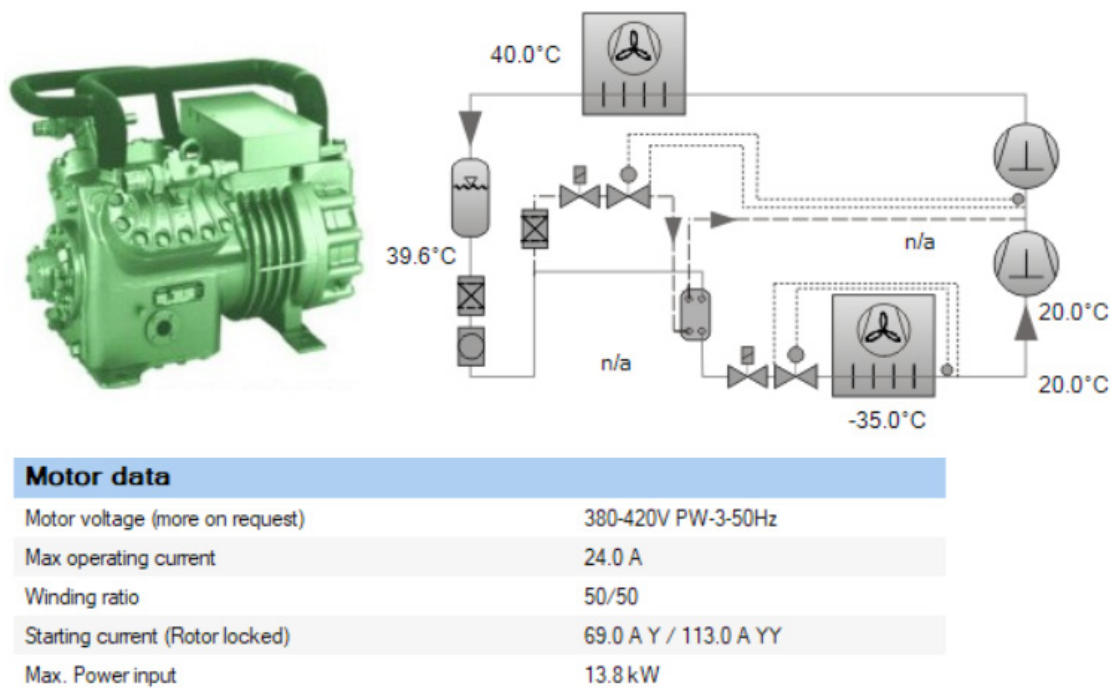


Figure 10: User interface of catalogue software from branded manufacturer of refrigeration system

3. CONCLUSION

The application of energy efficiency measures of electric motor drives are universally applicable. The shortest payback period (about 1 year) is achievable by adequate waste heat recovery (compressors, refrigeration systems, etc.), reactive power compensation (elimination of costs of excessive takeover of reactive energy, reduction of active losses, etc.), control of motor drives (pumps, fans), and the replacement of motors with a higher efficiency class. After determining the impact of individual consumers (groups of consumers) during the peak load, additional savings can be achieved by adequate organization of their work (time shift of work of individual consumers, moving the work of consumers to a period of lower tariffs, etc.). When implementing energy efficiency measures related to electric motor drives, electric motor can be considered independently, as the core of the system which may include variable speed drive such as fan, pump or compressor drive connected via gearboxes, and the total electric drive system, which includes piping system as well as all ancillary equipment such as compressed air tools. Depending on the approach, potential of energy efficiency improvement varies. Although the choice of highly efficient components can improve system efficiency, only the optimization of the entire system in terms of load and dimensional component selection can realize the full potential of energy efficiency improvements. The energy efficiency of motor drives is especially important from the aspect of asynchronous motors, which represent the largest consumers in industrial systems. Even a modest increase in engine energy efficiency contributes to a significant improvement in economic, environmental and strategic indicators. The reduction in energy consumption is directly reflected in the reduction of greenhouse gas emissions, especially CO₂ generated from electricity production.

JP Elektroprivreda BH d.d. - Sarajevo as a socially responsible company recognizes the importance of the efficiently energy usage and directs the business strategy of electricity market supply in direction of developing new services based on the exchange of technical and other experiences aimed at developing more effective control over electricity costs.

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BIOGRAPHY

Haris Čaušević received his degrees (first and second Bologna cycle) at the Faculty of Electrical Engineering, University of Sarajevo, Department for Automatic Control and Electronics in 2011 and 2015, respectively. He had partial employments at the Faculty of Electrical Engineering Sarajevo during study programme (as a demonstrator). He has been employed as an expert for technical information systems by JP Elektroprivreda BH d.d. – Sarajevo since 2015. Since 2015, he has been employed in two different departments in the JP Elektroprivreda BH d.d. – Sarajevo (2015–2016 and 2017–2018 in ICT department and 2018–now in Control and trading department) and part of numerous projects (maintenance, development, management). During 2017, he was employed by CET Energy where he gained some valuable experience in area of substation automation (protection and control). Areas of interest: IT, energy efficiency, automation, implementation of renewable energy sources etc.

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