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Professional paper/Stručni rad

COST-BENEFIT ANALYSIS OF FREQUENCY REGULATED ELECTRICAL DRIVES APPLICATION IN THERMAL POWER PLANTS - EXPERIENCES FROM TPP KAKANJ

ANALIZA ISPLATIVOSTI PRIMJENE FREKVENTNO REGULISANIH ELEKTROMOTORNIH POGONA U TERMOELEKTRANAMA - ISKUSTVA IZ TE KAKANJ

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Abstract: This paper describes the possible approaches to cost-benefit analysis of application of regulated drives using frequency converters on the characteristic drives in thermal power plants, as well as the positive and negative experiences so far. Some cost-benefit analyses (for fans and pumps) are made using the software applications and operating data from the control systems archive of production units. Where such data were not available (e.g. compressor), the data from operating books were used. The analysis was carried out for the thermal power plant TPP Kakanj.

Keywords: regulated drive, saving electricity, CO_2 emission reduction

Sažetak: Rad opisuje moguće pristupe analizi isplativosti primjene reguliranih pogona primjenom frekventih pretvarača na karakterističnim pogonima u termoelektranama, kao i pozitivna i negativna iskustva u dosadašnjem radu. Neke analize isplativosti (ventilatori i pumpe) urađene su primjenom softverskih aplikacija i korištenjem pogonskih podataka iz arhive upravljačkih sistema proizvodnih jedinica. Tamo gdje nije bilo takvih podataka (npr. kompresor), korišteni su podaci iz pogonskih knjiga. Analiza je izvršena za termoelektranu TE Kakanj.

Ključne riječi: regulisani pogon, uštede električne energije, smanjenje emisije CO_2

INTRODUCTION

Approximately 10% of the total electricity produced is consumed in operation of the thermal power plants (TPP). TPP Kakanj requires about 40 MW for its own consumption, of which about 90% goes to the electromotor drives with asynchronous cage motors at the 6 kV voltage level. Replacement of non-regulated electric drives with regulated drives with frequency converters has long been the practice in developed countries [1]. The main benefits of replacing non-regulated electric drives are:

- reduction of own consumption of electricity,
- reduction of CO_2 emissions,
- increasing the reliability of the technological process,
- financial profit.

While this practice is usual in industrial, water supply and various process plants, in thermal power plants the introduction in application of regulated drives and the replacement of old unregulated ones is not especially represented. According to the results of some surveys, the main reasons for this are:

- The traditional solutions of its own consumption (pumps, fans, mills...) are considered as proven, reliable and easily accessible, which is considered to be of the utmost importance in using frequency regulated drives.
- Lack of experience and confidence (traditionally trained driving staff) in new technologies.
- The desire for complete utilisation of the life of existing equipment.
- Inability to invest in new technologies and revitalize the existing equipment, and
- Application of hydraulic couplings, etc.

Since the application of frequency regulated drives in thermal power plants can achieve energy savings and reduced CO_2 emissions, some countries would reject above mentioned reasons faster than others. In addition, it is ex-

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pected that the price and reliability of new technologies will become more acceptable in the future. For powering own-consumption electromotors in modern coal-fired power plants, 8-10% of the unit's rated power is required.

Experience has shown that own consumption of thermal power plants can save 10-20% of the electricity with the use of frequency regulated electric drives; that is, the total efficiency of the unit can increase by up to 1%.
In TPP Kakanj, the first replacement of unregulated drives is achieved not because of economic benefits, but for technical and technological reasons.

- The first replacements were on the electromotors of rubber conveyors (capacity 1,000 tons/h), and the reason was the noise reduction produced by transporter passing through the village. Namely, the regulated drive automatically regulates the speed of the rubber conveyors; the transporter was slower with lesser amount of coal. The conveyor belt is thus better seated on the rollers and creating less noise.
- Flue gas fan motors (1,000 kW, 6 kV) were replaced by a regulated drive with frequency converter due to the fact that it could not respond to the pressure changes on the exhaust tract caused by dirt bags of the newly built hybrid flue gas filter.

In TPP Kakanj, up until now, regulated drives have been installed on flue gas fans on all units, and on Unit 6 on fresh air fan positions. The obtained effects were the motivation for the analysis of the benefits of their application to other unregulated electromotive power plants, too. Also, the analysis of their application on the electromotor drives the fan of fresh air in the other units, the electromotor drives the feed pumps of boilers, and the electromotor drives the dry screw compressor for producing air transport of separated fly ash.

Below are the results of analyses of the applicability of regulated electromotors (by installation of frequency converters) at the positions of the fresh air fan (630 kW), boiler feed pumps (2,000 kW) and screw compressors (1,250 kW).

The analysis was done using the operating system data from the control system (Teleperm XP), and the Fan Save and Pump Save software applications.

1. COST-BENEFIT ANALYSIS

1.1. Application of the fresh air fan positions

The current efficiency of the fresh air fan's electrical drive in the block 5 Kakanj observed in the period from June 8, 2009 to May 17, 2010, with the 1-hour observation resolution. For the analysis and evaluation of energy efficiency, and economic and environmental benefits, used the software application 'Fan Save 44 Energy saving calculator for fans' whose display analysis results are given in Figure 1.

All data in the period of observation are downloaded from the management system Teleperm XP and can be treated as completely reliable.

The application of the regulated drive ACS800-07-0750-7 was analysed. Table I shows the data on the work profile of the regulatory wreath in the period from 8 June 2009 to 17 May 2010 with a 1-hour resolution.

Table I: Work profile regulation wreath of the fresh air fan (left side)

Operating profile (%)	Total time openness of regulation wreath (h)	Size openness of regulation wreath (%)
1	122.6	100
2	131.4	> 90
8	657	80-90
40	3,495.2	70-80
44	3,819.4	60-70
2	210.2	50-60
1	96.4	40-50
2	184	30-40
1	43.8	20-30

Table II presents the technical indicators obtained in the analysis.

Table II: Technical data obtained by using a regulated drive on fresh air fans

Specific fan power	8.7 kW/(m^3/s)
Saving electricity	37.7%
annual consumption of electricity: with regulatory wreath with regulated drive	 2,494.00 MWh 1,555.00 MWh
Annual saving of electricity	940 MWh
Annual reduction of CO_2 emissions	1,034 tons

Table III presents the indicators of economic and environmental effects, obtained as to the outcomes of the aforementioned software application.

Net Present Value (NPV) is a standard measure used to compare the economic effects of the project. NPV of the investment project is the difference between the present value of future revenue from the project and the present value of its future costs.

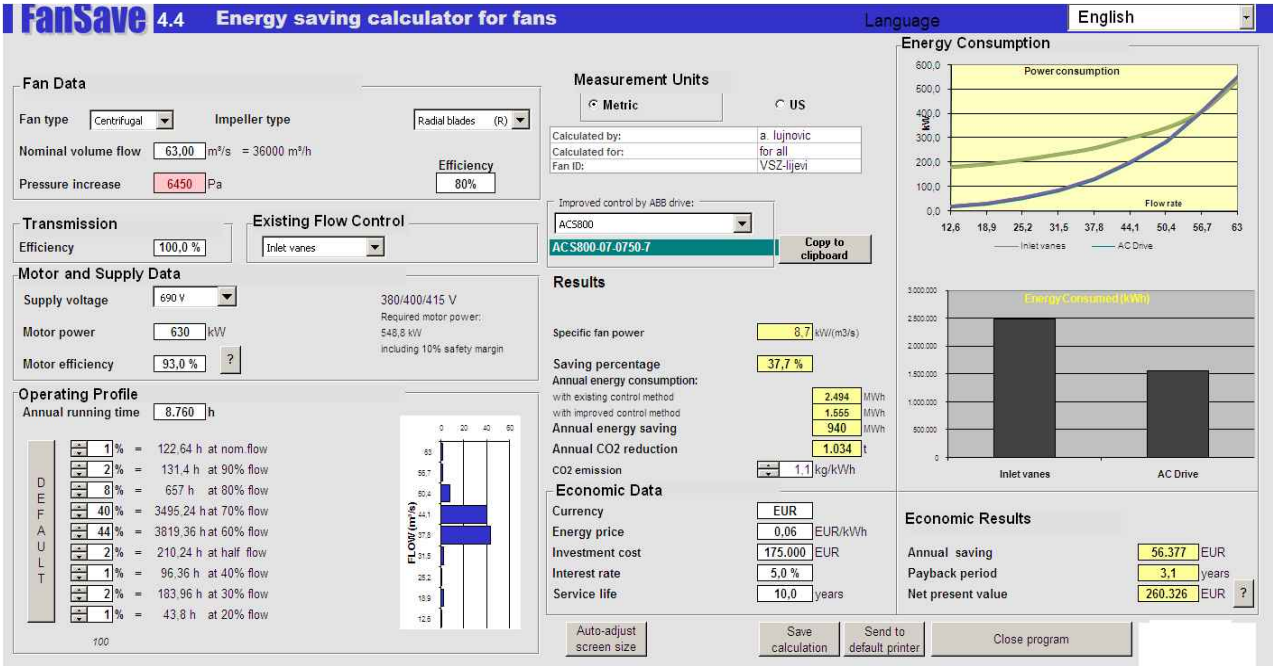


Figure 1: View of the results obtained in the software application 'Fan Save 4.4 Energy saving calculator for fans',[2]

Table III: Financial assumptions and results achieved by applying the regulated drive of fresh air to the fan

ASSUMPTIONS		RESULTS ACHIEVED	
Electricity price (EUR/kWh)	0.06	Annual saving (EUR)	56,377.00
Amount of investment (EUR)	175,000.00	Net present value (NPV) (EUR)	260,326.00
Interest rate (%)	5		
Lifetime (year)	10	Payback period (year)	3.1

Figure 2 shows the load characteristics of the unregulated electromotor (red) and the regulated electromotor of the fresh air fan (blue) realised by applying the frequency converter.

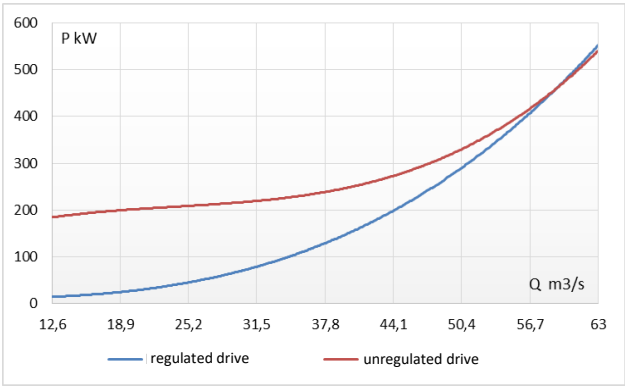


Figure 2: Load characteristics of the fresh air fan

Figure 3 shows the comparison of annual electricity consumption of unregulated and regulated fresh air fans.

Load characteristics and consumption are derived as a result of the applied software application [2].

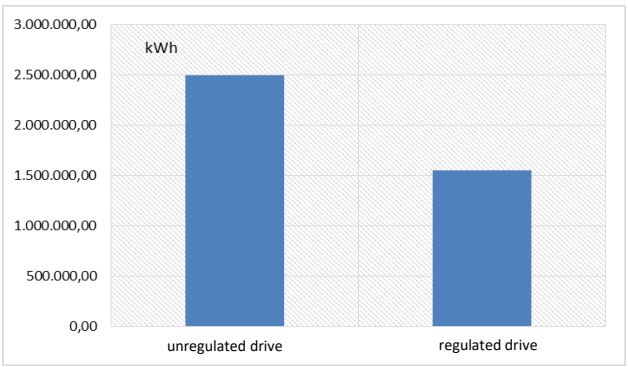


Figure 3: Comparison of annual electricity consumption

1.2. Application to the position of the boiler feed pump

The main feature of the feed pump is that, in addition to normal supply, it must be able to, in rare but possible situations, increase your usual supplying water boiler by 10-25%, depending on the design of the boiler and the

applied regulations. Therefore, this pump must always be designed with a high margin of safety, which practically means that it is mainly under-loaded. It also offers great potential for electricity saving. Since there is no data on actual consumption as a function of speed, and no clearly identifiable profile of consumption for a longer period of time, a rough estimate was made using the software application 'Pump Save 4.1 Energy saving calculator for pumps'. The results of this use are presented in Figure 4.

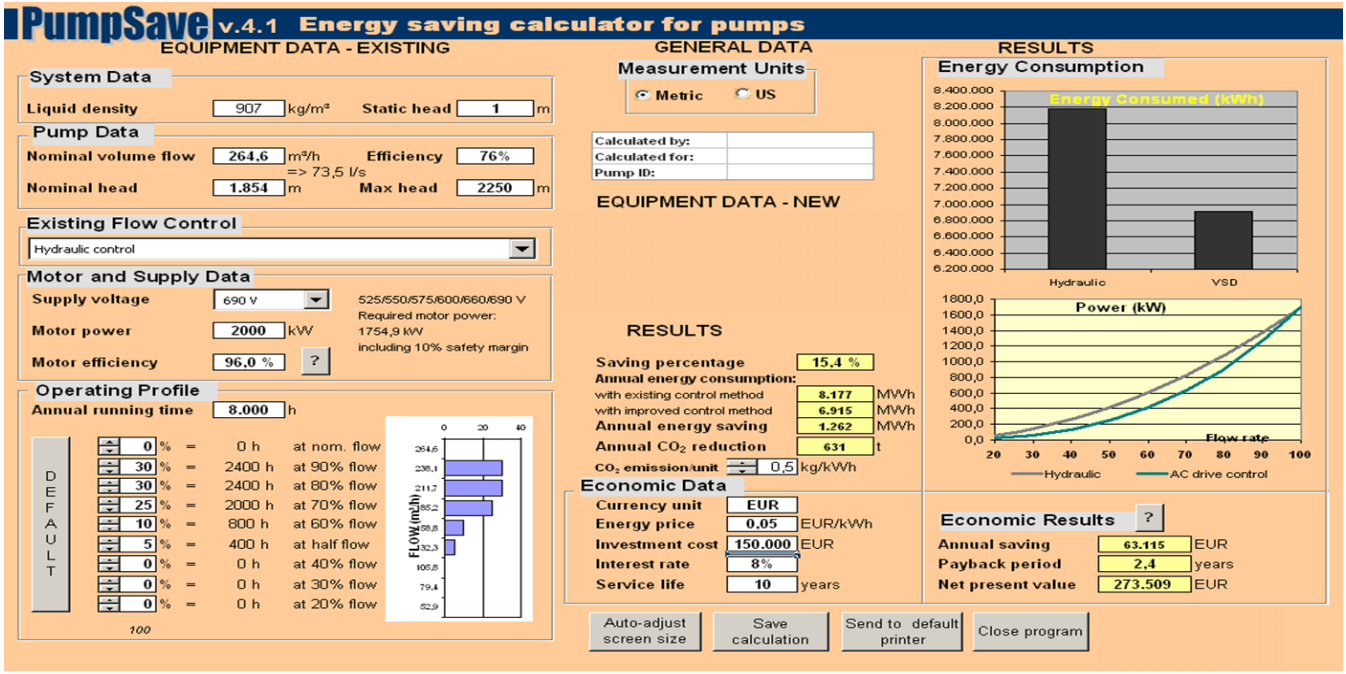


Figure 4: Showing the results on the software application 'Fan Save 4.4 Energy saving calculator for pumps' [2]

The 'Pump Save' application assumes the usual functional dependencies that apply to the pumps, i.e. $H \sim \omega^2$, $P \sim \omega^3$, $Q \sim \omega$, where H height is supplied (i.e. pressure, bar), P power (kW), n speed of rotation (rpm), and Q volume of air flow (m^3/h).

The analysis was made on the basis of available data from Unit 5. All data on the operating profile of the regulating valve of the supply water during the observation period are taken from the Teleperm XP control system.

Table IV presents data of the operating profile on the control valve in the observed period of the past 8,000 hours.

Table V presents economic and environmental effects obtained by the use of the software application.

Table VI shows the financial assumptions and the results of economic effects, which were obtained by applying the software application.

Table IV: Regulation valve operating profile

Operating profile (%)	Total time of regulating valve (h)	Size openness of regulation valve (%)
30	2,400	100
30	2,400	>90
25	2,000	80-90
10	800	70-80
5	400	60-70

Table V: The results obtained using the regulated drive on the feed pump

Saving electricity	15.4%
Annual consumption of electricity:	
with regulation valve	8,177.00 MWh
with regulated drive	6,915.00 MWh
Annual saving of electricity	1,262.00 MWh
Annual reduction of CO_2 emissions	631 tons

Table VI: Financial assumptions and results achieved by applying a regulated electric drive to the boiler feed pump

ASSUMPTIONS		RESULTS ACHIEVED	
Electricity price (EUR/kWh)	0.06	Annual saving (EUR)	63,115.00
Amount of investment (EUR)	150,000.00	Net present value (NPV) (EUR)	273,509.00
Interest rate (%)	5		
Lifetime (year)	10	Payback period (year)	2.4

Figure 5 shows the P-Q characteristic of the unregulated and regulated electromotor drive of boiler feed pump. Characteristics are the result of the applied software application [3].

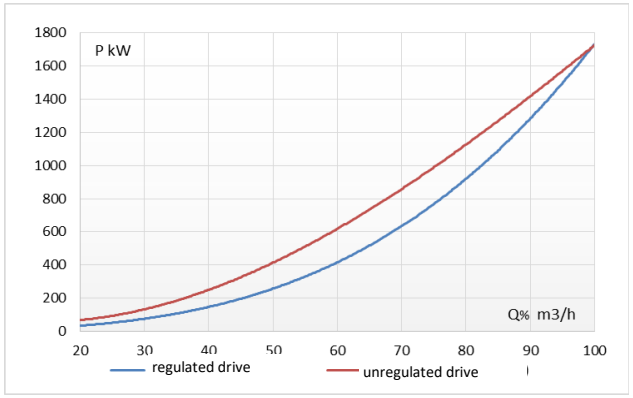


Figure 5: Load characteristics of the boiler feed pump

Figure 6 shows the annual electricity consumption of unregulated and regulated electro motor drive of boiler feed pump of Unit 5.

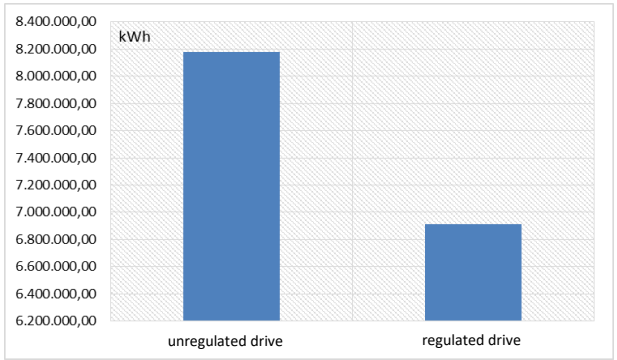


Figure 6: Comparison of annual electricity consumption

The same result would have been obtained if the analysis was to be accessed in such a way as to determine the operating point of the normal pump load during the stable operation of the Unit 5. Pump flow regulation by changing the speed of rotation on the Q-H pump characteristics, changing the operating points as shown in Figure 7 ($n_3<n_2<n_1$). The load characteristic (dotted line) does not change, and the new pump operating points are located at the intersection of these curves.

As can be seen from the Q-η characteristics, the efficiency of the pump (η) is only slightly altered by decreasing the speed, but changes the flow of the pump or the required power of the electric drive much more. Use of a frequency converter reduces engine losses and avoids losses of the hydraulic coupling, because it then becomes unneeded.

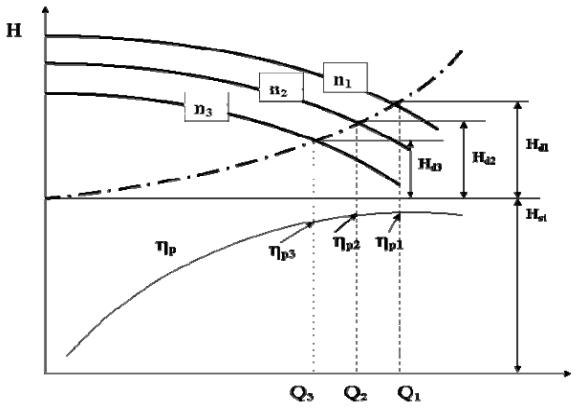


Figure 7: Characteristics of boiler feed pump [4]

In case of hydraulic couplings, the pump speed is regulated in a narrow range, up to the rated motor speed, as shown in Figure 8.a). The operating range of the hydraulic coupling of the boiler feed pump is from 2,400 to 2,900 rpm.

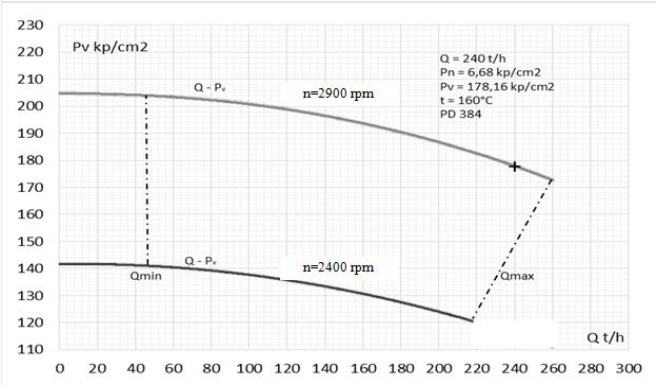


Figure 8a): The operating range of the hydraulic coupling of boiler feed pump [4]

Figure 8.b) and Figure 8.c) show Q-η and Q-P characteristics of the boiler feed pump on Unit 5 of TPP Kakanj.

Rated parameters of the pump are:

Q_n = 73.5 t/h
n_{nom} = 2,900 rpm
T = 160 °C
P_n = 1,850 kW (from the chart)
ρ = 0.9074 g/cm3
η = 76%

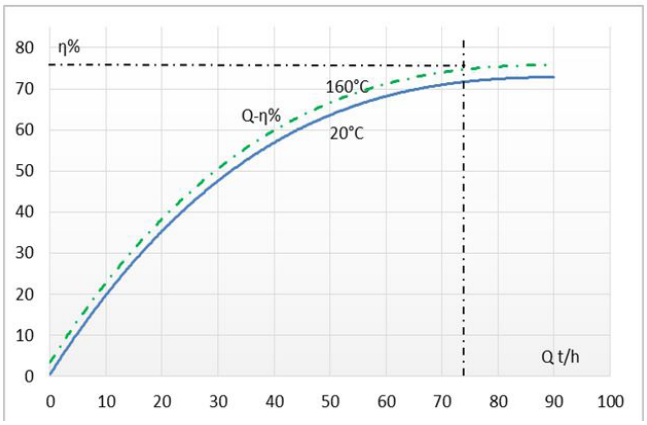


Figure 8.b): Q-η boiler feed pump characteristics [4]

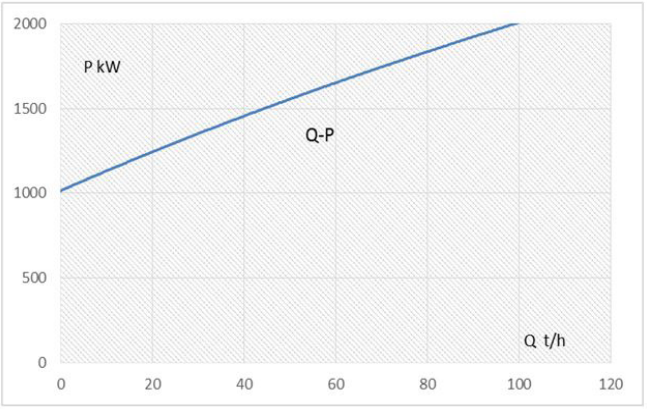


Figure 8-c): P-Q characteristic of the boiler feed pump [4]

The basic nominal data of the boiler electromotor are: power 2,000 kW, voltage 6 kV, current 223 A. During the period of observation, in a stable and ordinary work of Unit 5, electromotors feed pump amounted 140 A, which corresponds to the three-phase asynchronous motor of 1,200 kW.

The curve, obtained from the software application 'Pump Save', shows that the effect in 1,200 kW feed pump achieved 85% of the flow. For this flow, the power to be achieved by a regulated drive with a frequency converter would not exceed 1,000 kW, as shown in Figure 5.

1.3. The application of the position of the air compressor

In TPP Kakanj, five single-stage dry screw compressors type ZK 510 have been installed with symmetrical rotor profile, used for compressing atmospheric air at a pressure of 0.40 MPa. Exhausted compressed air temperature is 190 °C. The compressors were installed in 1987 and are used for the production of compressed atmospheric air which drains the ashes separated from the flue gases. The compressors were tested at a maximum exhaust temperature of 205 °C, at which a pressure of 0.42 MPa was achieved. Each of the screw compressors has a main oil pump driven by a secondary compressor rotor, and an auxiliary oil pump that only serves to start and stop and has its own electromotor. The compressor does not have a gearbox (it is made directly through the gear coupling), the rotation of the electromotor is the same as the rotations of the main compressor rotor. The production of air at the nominal rotation speed (2,975 rpm) of the electromotor or compressor is 16,300 m^3/h with a power output of 1,080 kW. Screwed dry compressors run three-phase asynchronous electromotors with a cage rotor, type 2V 182-02 H (normal performance), 1,250 kW, 6 kV, 50 Hz, 2,975 rpm, IP44, cooling ICW 37 A 71, form IM 731, rated power factor cosφn=0,86, I_n=147 A. Its efficiency at 100% load is 95.2%, with rated torque of 3,991 Nm. In TPP Kakanj, there are three production units in operation: unit 5-110 MW, unit 6-110 MW and unit 7-230 MW. For simultaneous operation of units 5, 6 and 7, the production of air can only be provided by the two ZK510 screw compressors. But unfavourable combinations occur when all three blocks are not working, and then compressed air must be released into the atmosphere. Air compressed in the compressors is drained to a common air pressure system collector with low flow capacity (approx. 10 m^3/h). Compressors do not have a wide range of power regulation. The control is a two-position one: all or nothing, i.e. or 100% or 0% (when the compressor works in a completely unloaded state) power. The control is performed by damping through the damper and by simultaneously releasing the compressed air into the atmosphere through the overflow valve.

In the compressed air network, a measuring converter is installed, which switches the electromagnetic valve on or off the air supply, based on the set pressure value, Apart from the considerable energy losses caused by the overflow of expensive compressed air, there is significant instability in the air system, which is reflected by the high volatility of the pressure on the buoyancy. Since the compressor station does not have a control system with archived data on air production and consumption, the analysis was carried out by monitoring the individual compressor operating hours (number of working hours of all compressors in operation) and the periods of operation of individual production units in the previous year through the books of the operating personnel, as shown in Figure 9.

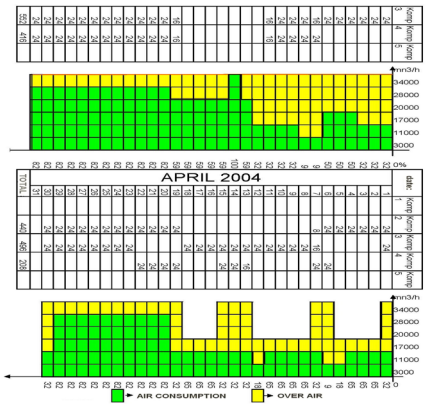


Figure 9: Monitoring the production and consumption of air through the workbook of staff [5]

Since the compressor station does not have a control system with archived data on production and air consumption, the analysis was conducted by monitoring the individual compressor operating hours (number of working hours of all compressors in operation) and the periods of operation of individual production units in the last year, period of operation of certain production units in the previous year, the book drive.

The difference in the annual energy consumption of a regulated drive using a frequency converter against an unregulated existing plant is 3,016.48 MWh. For the price of electricity 1 kWh = 0.06 EUR, annual savings are about 180,000 EUR. Therefore, the investment in the amount of 500,000 EUR-would see its return in 2.8 years [5].

The results of the analysis of electricity consumption are presented in Table VII.

Table VII: Calculation of Electricity Consumption

Air consumption m^3/s		Profile of work (%)	Hours of work (h)	Electricity consumption unregulated drive (MWh)	Electricity consumption regulated drive (MWh)
1	2	3	4	5	6
9%	0.43	0.75	121	45.04	16.15
18%	0.85	0.75	121	55.76	19.57
32%	1.51	14.46	2,348	1,248.09	478.10
50%	2.36	14.46	2,348	1,389.42	619.76
59%	2.79	11.72	1,903	1,216.48	654.81
65%	3.07	7.73	1,255	846.76	560.04
82%	3.87	29.93	4,860	3,393.25	2,782.34
100%	4.72	20.20	3,280	2,330.93	2,378.50
Total:		100	16,236	10,525.73	7,509.26

2. EXPERIENCE OF APPLICATION

The TPP Kakanj is now regulating drives with frequency converters at the positions of the flue gas fans.

A large number of frequency converters are also used on electromotor drives, powered at the voltage level of 400V. These are electromotor drives for rubber conveyors of the overall coal transport system; feeder conveyers in boilers and other. The advantages brought by the application of frequency converters in these examples are:

- Increasing the quality and safety of the technological process: maintaining a negative pressure in the boiler (as the regulated variable), managing the number of fan rotations. Use of all damping control flaps on flue gas ducts has stopped.
- Electricity savings: with the elimination of damping elements from the technological process, significant savings in electricity consumption have been achieved. At the flue gas fan position of Unit 5, the consumption amounted to about 8,000 kWh for 24 hours, while at that position before the converter installation it was over 12,000 kWh.
- Saving on maintenance of mechanical and electrical equipment: large savings are obtained on the maintenance of mechanical equipment on the coal transport system. Hydraulic coupling and gear units are excluded from the use of frequency converters. Loss of rubber strips when starting the transport system is prevented. The operation of the unloaded conveyor at reduced speed now generates a lower noise level and prevents damage to rollers.
- Possibility of remote control and collect operating data: by connecting the driver frequency converter and control system on the units, it is possible to achieve remote control to the full extent, and the data and operating events can be archived and used for later analysis and evaluation.

The choice of implementation using air cooled frequency converters proved to be the only and biggest deficiency in exploitation so far. Namely, this design requires constant engagement to maintain effective ventilation to ensure satisfactory cooling of the converter. The required amount of cooling air is 8,000 m3/h per 1,000 kW converter. Dust is always present at the power plant entrances, and such a high air flow-through brings in the dust into the rooms and converter cabinets, causing quick soiling of the air filters. This reduces the amount of air flow through the converter cabinets and creates conditions for overheating of components of the rectifier frequency converter, or the occurrence of failures.

Figure 10 shows what additional equipment is needed for ventilation and cooling of the chamber where two 2,500 kW powered air-cooled frequency converters are placed. Problems are manifested in the summer period when converters become 'weak links' and endanger the reliability of the thermal power plant.



Figure 10: Fan chambers for cooling of frequency converters.

Water cooled converters are initially slightly more expensive than air-cooled ones, but require additional cooling equipment, so the difference is no longer significant. Therefore, in such conditions, water-cooled converters are certainly a better choice, especially as demineralised water is already being used for cooling in other technological processes of the thermal power plant.

3. CONCLUSION

In thermal power plants, where drives are operational throughout the year, return period is short and therefore replacement of unregulated drives with by introduction of regulation applying frequency converters in such plants is a cost-effective process. It is common for a production unit to operate 11 months or 8,000 hours per year. Investment return is short and takes 2-3 years.

The analysis showed that the installation of regulated electric drives in positions of fan, feed pumps and screw compressor is economically and technologically fully justified, because:

- they can achieve significant energy savings,
- a short payback period,
- reduce CO_2 emissions,
- the technological process is easier: Starting the engine and pumps is slow, the electrical and machine components of the drive are protected by the converter.

Experience has shown that there was a problem in provision of satisfactory converter air-cooling at the power plant. Therefore, it is necessary to carefully assess the real environmental conditions of the location when choosing an converter type.

Our experience shows that though selection of water-cooled frequency converters was a better option.

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BIOGRAPHY

Adem Lujnović was born in 1961 in Kakanj. After completing the Secondary School of Electrical Engineering in Sarajevo, the department of electronics, he graduated from the Faculty of Electrical Engineering in Sarajevo, Department of Power Engineering in 1987. Since the end of the study, for almost 30 years now, he has been employed at TPP "Kakanj". He has extensive experience in maintenance and modernization of electrical facilities and electric machines. At the moment, he holds the position of a Chief Engineer for the reconstruction of the electric facilities. He was the leader or participant of several reconstruction and modernization projects in the TPP ''Kakanj''. He was a member of expert teams of JP Elektroprivreda BiH engaged in projects of modernization of electric plant and energy network systems.

Sabina Dacić-Lepara was born in 1982 in Sarajevo, where she completed elementary and high school education. She graduated at the Faculty of Electrical Engineering in Sarajevo, Department of Automation and Electronics in

2008, and received her master's degree in technical sciences in 2014. As a scholar of Energoinvest d.d. Sarajevo, she was employed in this company until 2014, worked on designing and delivering control systems, supervision and instrumentation systems in complex industrial processes. Since 2014 she has been employed by the JP Elektroprivreda BiH, where she works as a consultant in preparation and construction of small renewable energy power plants. She has experience of eight years in working with students at higher education institutions in the field of electrical engineering, system design, power grids, system and economic engineering, and computer algorithms. She is the author and co-author of a number of scientific papers published in indexed journals.

Munib Terzo was born in 1956 in Sarajevo. He finished the high electrotechnical school, department of electronics, in Sarajevo. Since the end of the high school, he was permanently employed in Energoinvest. During his career he has worked on different jobs, participated in numerous projects in the field of automatic control and application of frequency converters in electric drives in thermal power plants. In 1999 he founded own company Instruments d.o.o., Sarajevo, which primarily deals with the provision of services in the field of industrial automation and process control.