ANALYSIS OF THE ELECTRICITY PRODUCTION POTENTIAL IN THE CASE OF RETROFIT OF STEAM TURBINES IN A DISTRICT HEATING COMPANY

by

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Original scientific paper
UDC: 621.195:621.311.22
DOI: 10.2298/TSCI100415027B

Today, in Serbia there are several sites with installed combined heat and power facilities. The most of these plants, for various reasons, do not produce electricity. One such plant is "Energetika" (Kragujevac, Serbia), which is primarily a district heating company. Steam generator in the plant has been installed in the 1970's and has worked in one short period of time. Installed steam turbines are 8 MW and 20 MW rated power. "Energetika" in accordance with the general trend of increasing energy efficiency of production process initiated revitalization of the plant. This revitalization started with a study which approach and the results are briefly given in the paper. All results show that retrofit of facility should be acceptable for the management. Developed scenarios indicate that in the case of the limited resources optimal retrofit should start with smaller turbine (8 MW rated power) then after providing the funds should continue with the retrofit of 20 MW turbine.

Key words: *district heating, steam turbine, combined heat and power*

Introduction

Despite the fact that the use of primary energy only for a low temperature heat is thermodynamically and economically unjustified, Serbian district heating (DH) systems use primary energy (coal, gas, heavy oil and biomass) mainly for heating of the hot water or steam.

One of the power plants of "Energetika" from Kragujevac is located at the site "Matična lokacija". Its historical development and mission is different from the rest power plants in Serbia. It started development as an industrial plant, then became an industrial-municipal and today has all the attributes of municipal DH plant. During 1970's steam-turbine

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block for combined production of electricity and thermal energy (CHP) was installed. The block consists of two steam turbines of nominal power of 8 MW_e and 20 MW_e.

Today "Energetika" as district heating (DH) company (in addition to production capacity on site "Matična lokacija") has five smaller boiler houses which are mainly equipped with hot water boilers (tab. 1).

Although all boiler houses have potential to improve energy efficiency through the introduction of co-generation or tri-generation, the economic feasibility of such investments is not the subject of this paper. The paper is based on a study that is primarily focused on the possibility of reconstruction of the existing steam-turbine block on site "Matična lokacija" and the economic aspect of such action.

Table 1. Boiler houses of "Energetika" from Kragujevac and their installed power

	1	2	3	4	5	6
Boiler house	Matična lokacija	Bolnica	Erdoglija	Promet i servis	Bubanj	Maglićka
Installed capacity	310	30.47	23.9	5.76	1.4	0.6
Boiler type	Steam	Hot water, steam	Hot water	Steam	Hot water	Hot water

Boiler house "Matična lokacija" consists of the five processing units that make up the boilers, steam turbines and other equipment and that:

– Boilers (tab. 2):

Table 2. Installed boilers on site "Matična lokacija"

	Unit	K – 1	K – 2	K – 3	K – 4	K – 5
Steam production	T per h	32/40	32/40	64/80	64/80	120/150
Pressure	bar	37	37	37	37	37
Temperature	^{o}C	550	550	550	550	550
Fuel		NG	NG	Coal	Coal	Coal
Heat power	MW_t	112	63	31.5	31.5	63

– Steam turbines:

- turbine unit no. 1 (8 MW_e, 10 MVA, 6kV),
- turbine unit no. 2 (20 MW_e, 25 MVA, 6kV) (figure 1),

Figure 1. Steam turbine (20 MW) today

– Other equipment:
  – facility for the distribution of steam for industry (15 bar, 250 °C, 6.5 bar, 250 °C),
  – facility for the distribution of hot water for (140/100 °C) the plants of the former company "Zastava" group,
  – facilities for the distribution of hot water for heating of the city of Kragujevac, and
  – facilities for the distribution of electricity for its own needs and the needs of the former company "Zastava" group.

The annual consumption of electricity and fuel on site "Matična lokacija" (energy equivalent) are shown in table 3.

Today "Energetika" does not produce electricity. Steam-turbine block was in the occasional use until 2000, when detailed inspection of the turbines was made by the manufacturer of the turbines. Due to lack of investment and low prices of electricity turbines are still not operational [1].

During 2009 Serbia ratified the necessary legislation which provided higher prices of electricity supplied from CHP production (feed – in tariffs). That motivated "Energetika" to examine the viability of investment in reconstruction and modernization of the steam-turbine block.

Table 3. Summary of fuel consumption by fuel type in 2002

	Consumption		Equivalent energy		Costs	
		Unit	[TJ]	[%]	[€]	[%]
Coal	92 729	t	1 366	56%	Coal	92 729
Heavy fuel	2 040	t	83	3%	Heavy fuel	2 040
NG	19 036 476	Nm^3	633	26%	NG	19 036 476
Electricity	96 180 223	kWh	346	14%	Electricity	96 180 223
Total			2 430	100%	Total	

Beside the legislation change, change of heat energy demand in past period was one more reason for CHP investment estimation. In the transition of the former company "Zastava" group (for which needs boiler house "Matična lokacija" was build) a number of smaller companies were established. These companies have started to independently produce energy for their own needs. The biggest of the former consumers of thermal energy, the company Fiat Serbia (former "Zastava car factory"), bases its development on building its own large natural gas fired boiler house.

Described changes in the market, legislation and other legal circumstances required the preparation of study for the assessment of cost-effective investments in the modernization of the existing turbine block.

Analysis conducted

A conceded analysis included [2, 3]:
– quantification of power plant previous working regimes,
– analysis of thermal energy and electricity consumption of the power plant,
– analysis of differences between conceptual design of the plant and its actual state,

– reconstruction and modernization analysis of existing CHP facility, and
– economical analysis and the conceptual design for the proposed technical solutions.

Existing situation

"Energetika" in 2005 started logging technological data at specific points in the production. Hourly collected data are:

– pressure and temperature at the exit of the boilers as well as the production of steam from each boiler,
– flow and temperature of hot water for consumers,
– flow and amount of steam for steam customers,
– temperature, pressure and flow at different points of the system,
– ambient temperature,
– quantity of coal, oil and natural gas that are used in one shift (8 hours), and umerous other data that are estimated to be important for production planning on site "Matična lokacija".

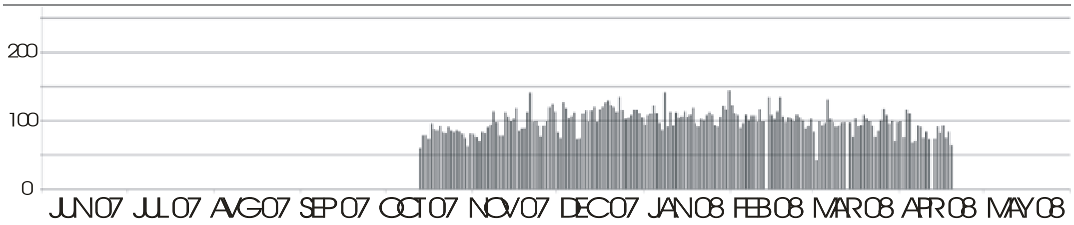


Figure 2. Daily heat load (MW) – heat load is city district heating only (from June 1, 2007 to May 31, 2008)

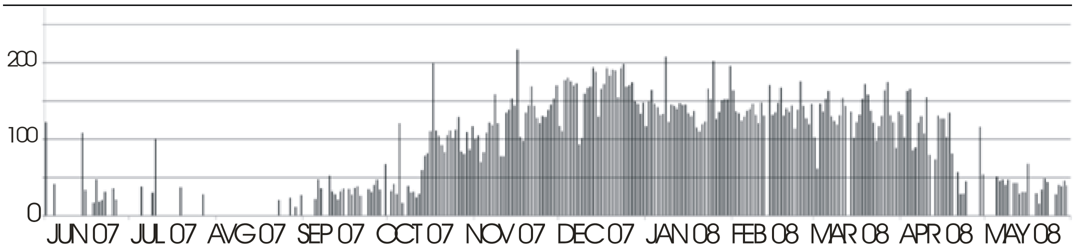


Figure 3. Daily heat load (MW) – heat load consists of city district heating plus water and steam for the technological needs of industry (from June 1, 2007 to May 31, 2008)

This database (Microsoft Access file) is used as a starting point for research and for quantification of previous operation of the boiler house "Matična lokacija". The database was converted to a Microsoft Excel spreadsheet for the analysis. From these data the following load diagrams (figures 2 and 3) are made (since DH and industrial consumption are separately measured and monitored, it is possible to separately determine and display their load and subsequently to define appropriate scenarios). All data in this paper are given for heating season 2007/2008 as illustration for performed analysis.

Based on the shown data conclusion could be drawn that the boiler house is oversized (installed capacity is 301 MW_t) for the current needs of district heating and industry. This conclusion entails the need to attract new customers in order to achieve greater engagement of production capacity. The potential for production expansion in the next period is seen in the former industrial users. To such big customers should be offered to buy heat and/or electricity as privileged buyers. In this way "Energetika" could increase the number of working hours which is important to increase electricity production, especially during the summer (when there is no need for DH).

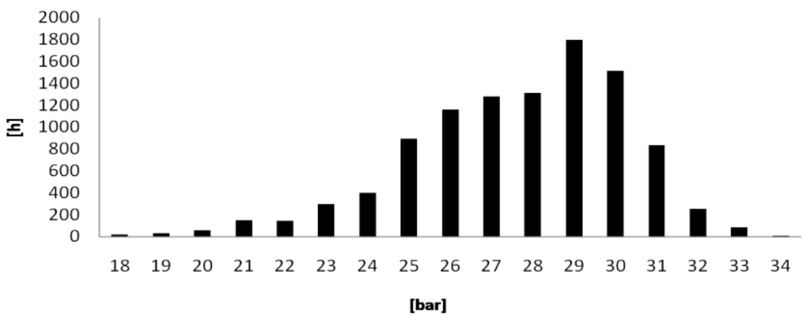
According to previous strategy 79% of capacity on site “Matična lokacija” are coal powered boilers. These boilers are seen as main source of power for combined production of heat and power.

The following figure 4 shows the dependence of boiler K – 3 (coal fired) pressure and the number of working hours in the reporting period (from 2005 till 2009).While the display is given only for the boiler K – 3, this diagram is similar for all the other boilers at site “Matična lokacija”. It is clear that boiler’s operation regime (in the observed period) have shifted from projected 37 bar to average 29 to 30 bar. Boiler virtually has no working hours in the designed regime. This is due to boilers and additional equipment age, *i. e.* the necessity to keep the boilers operating in such a way to avoid failure.

According to the opinion of experts from the Faculty of Mechanical Engineering in Kragujevac and management of the "Energetika" the following problems, apart from boilers condition, restrict energy efficiency increasing and potential electricity production [4]:

- High percentage of old pipelines in the DH distribution system,
- Inadequate measuring instruments in all phases of production, distribution and consumption,
- Obsolete and dysfunctional boilers control system,
- Lack of modern control systems for the DH management according to the heat demand;
- Lack of participation of variable frequency drive (VFD) motors for pumps, compressors, fans, *etc*.

Figure 4. An example of established correlation between steam pressure in the boiler K–3 and time period (number of working hours) during the period January 2005 – October 2009



These and other facts are taken into account in determining the potential for electricity generation as an aggravating factor.

Determining the potential for electricity production

Analyses were performed for two cases:

1) Thermal energy (steam) is used exclusively for the needs of the city district heating, and
2) Thermal energy (steam) is used for the heating needs of the city DH and the industry – in the manner in which they used steam in the reported period (2005-2009).

Furthermore, each of these cases is analyzed in three scenarios:

1) Only 8 MW turbine repaired,
2) Only 20 MW turbine repaired, and
3) Both turbines repaired (8 + 20 MW).

This approach (and thus obtained six scenarios) provided:

– A clear insight into the most cost-effective scenario,
– The reconstruction plan according to the available investment, and
– The possibility of planning of the reconstruction of turbines in two stages in the financially optimal way.

Processed data from the 2005-2009 were the basis for determining potential for CHP production at site "Matična lokacija". Since the data at the largest number of measuring points consist of:

– Temperature and pressure of fluids (steam and/or water) data,
– Current and/or voltages and/or consumed power data of motors and pumps, and
– Flow of hot water data for district heating system,

it was possible to determine all of the thermodynamic parameters necessary for the analysis of the possibilities for CHP production at site "Matična lokacija". For calculation of the steam enthalpy produced by the boilers K–1, K–2, K–3, K–4 and K–5 was used "Excel module Water97_v13.xla for Properties of Water and Steam". This add-in has proved to be very accurate in a wide range of temperatures and pressures for the dry-saturated and wet steam. Determination of enthalpies of steam is calculated on the basis of measured values of pressure and temperature.

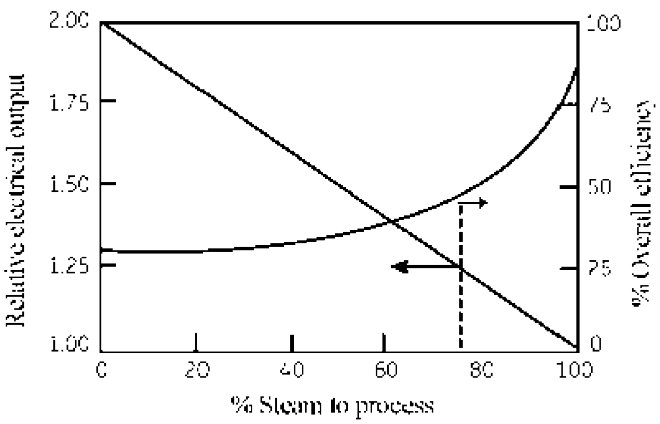


Figure 5. Dependence of the steam turbine performance from demand

As a base for defining the potential for electricity generation was used the diagram shown in figure 5 [5]. This diagram is used for further analysis in analytical form and it gave us theoretical basis for defining electricity production potential.

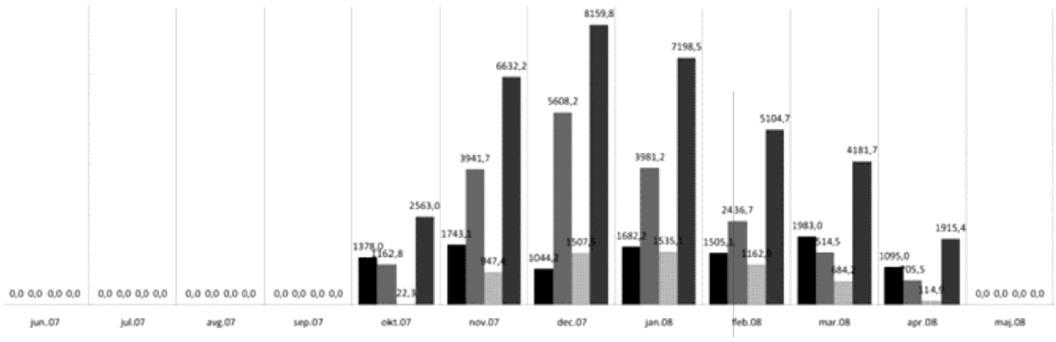


Figure 6. Scenario of monthly electricity production (MWh_e) in the heating season 07/08 – where heat load makes a city district heating

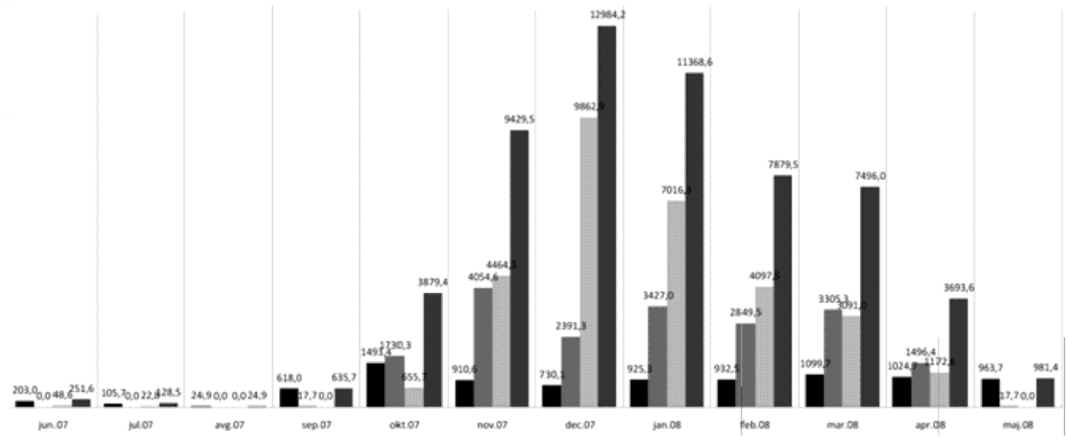


Figure 7. Scenario of monthly electricity production (MWh_e) in the heating season 07/08 – where heat load consists of district heating plus water and steam for the technological needs of industry

In the following figures are given the electricity production per heating season in case of retrofit of the both turbines.

Diagrams are also the result of the data used for diagrams of the load per heating season. Legend for the figures 6 and 7:

– First bar (black) – Monthly electricity production (MWh_e) generated, according to the scenario, by 8 MW turbine only,

- Second bar (grey) – Monthly electricity production (MWh_e) generated by 20 MW turbine only,
- Third bar (light grey) – Monthly electricity production (MWh_e) generated by simultaneous work of both turbines (20 MW + 8 MW), and
- Fourth bar – Total monthly electricity production; the estimated amount of generated electricity (MWh_e) in the reporting month, *i. e.* black bar + grey bar + light grey bar.

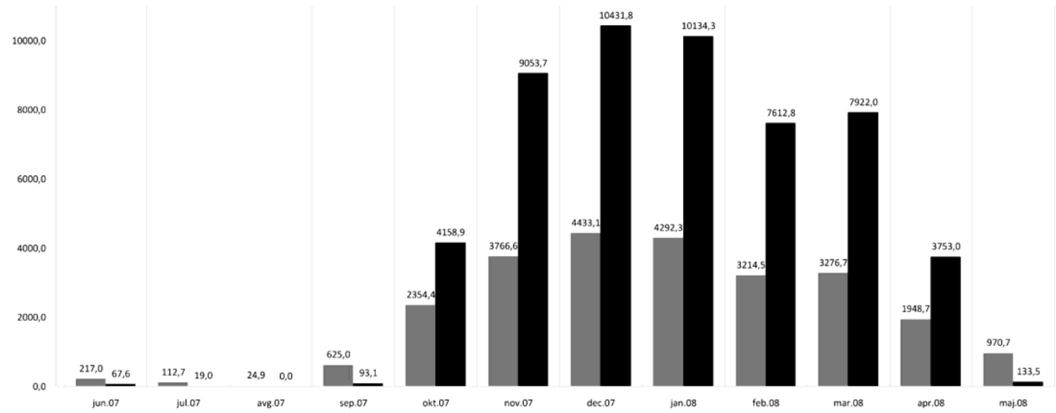


Figure 8. Monthly electricity production (MWh_e) in the heating season 07/08 in case of retrofit of 8 MW turbine only (grey bar) or 20 MW turbine only (black bar). Heat load assumed is the city district heating

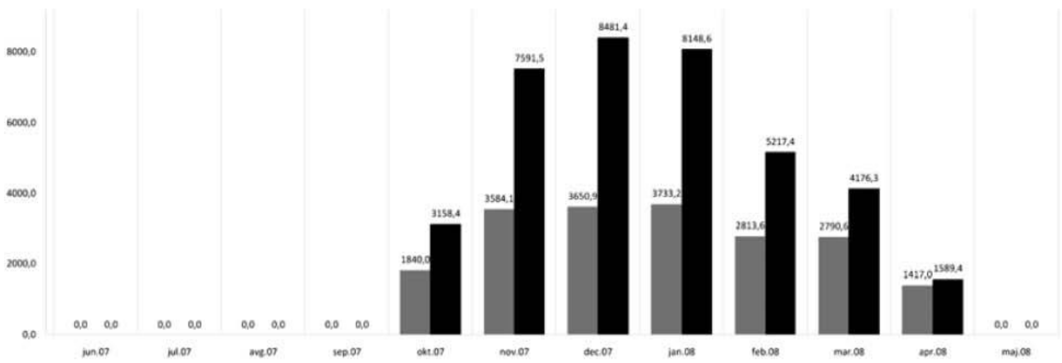


Figure 9. Monthly electricity production (MWh_e) in the heating season 07/08 in case of retrofit of 8 MW turbine only (grey bar) or 20 MW turbine only (black bar). Heat load assumed is the city district heating plus water and steam for the industry

In the pictures that follow (figures 8 and 9) is given estimated monthly production of electricity (MWh_e) in the heating season 07/08. These estimates are given for two special cases, as explained in previous text:

- Special case 1 – retrofit of the 8 MW turbine only (shown in grey bars), and
- Special case 2 – retrofit of the 20 MW turbine only (shown in black bars).

According to the same analogy estimates are made for the other three heating seasons (05/06, 06/07 and 08/09) but due to lack of space are not shown in this paper.

The proposed conceptual design

When CHP design was made in 1970's industrial consumption was high (followed by needs for high pressure steam).

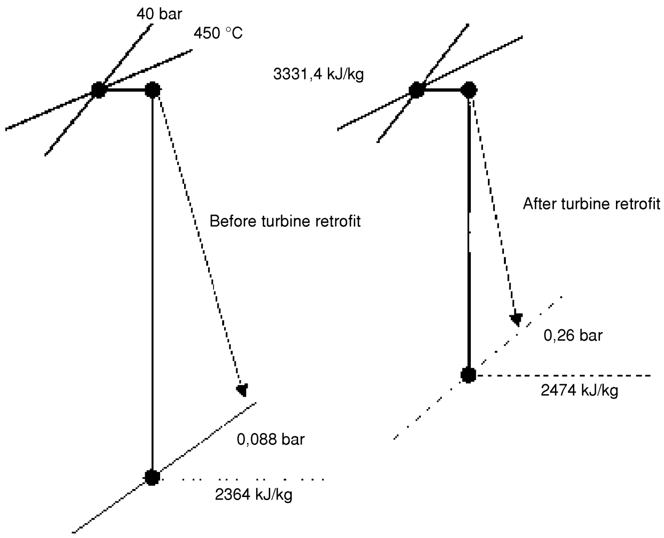


Figure 10. Thermodynamic parameters of steam at the entrance and exit of 20 MW

Today the main consumer is hot water DH system. This led to a necessity to redesign original conceptual design. The optimum technical and financial solution (taking into account the reality of the situation) is to consider the DH as a major consumer of generated thermal energy in the future.

In order to ensure quality of supply for the existing DH consumers the parameters of the steam at the exit of the turbine are raised (figure 10) in regard to previous design from the 1970's. This will result in the increase of the heat delivered to the DH system in regard to original design and on the other hand it will decrease expected electricity production (again in regard to the planned production of electricity within an original design).

This decrease of electricity production should utilize boilers capacities and fuel consumption in an optimal way. Estimation is that the delivered power (with this new design) of steam turbine of 20 MW wouldn't exceed 19 MW while the power of 8 MW turbine wouldn't exceed 7 MW. Thus retrofitted system is expected to have an overall efficiency greater than 80%. On the next two figures 10 and 11 is shown proposed solution for the 20 MW turbine. The same analogy is used for the solution of 8 MW turbine.

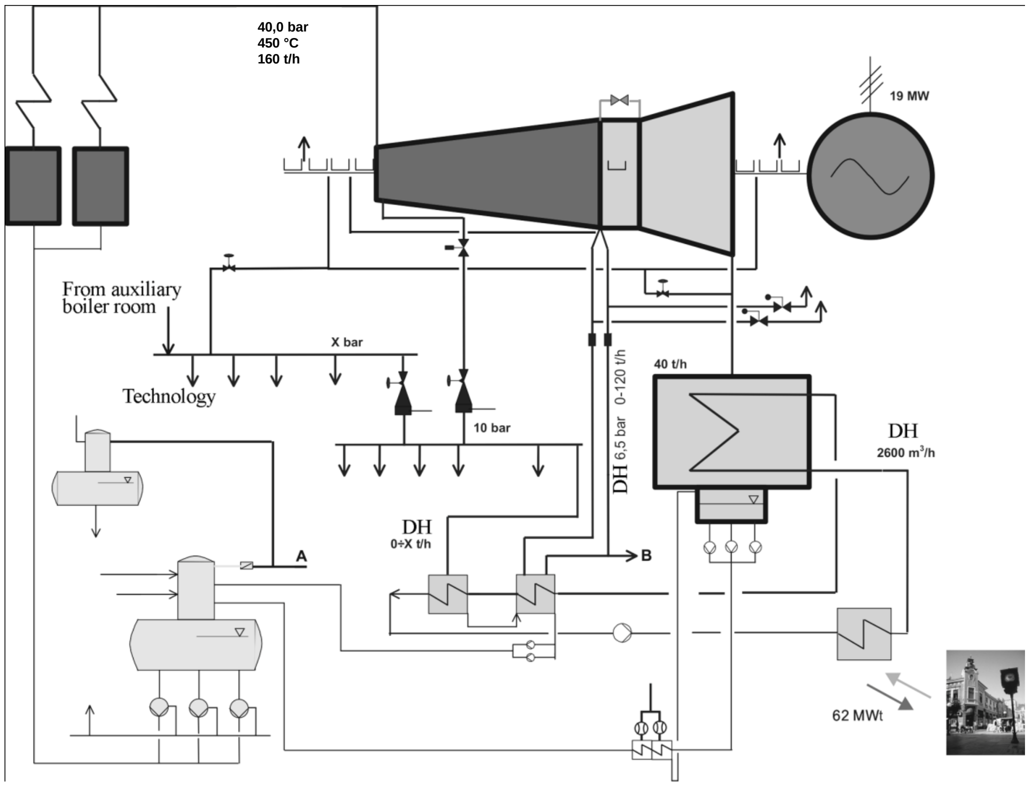


Figure 11. Conceptual design of the 20 MW turbine retrofit (19 MW)

Financial aspect of the investment

Financial aspect of the required investment is shown in table 4.

Table 4. Investment required for the retrofit of turbines and expected production of electricity (MWh_e)

	Investment [€]	Assumed electricity production [MWh_e per year]	
		DH	DH + Industry
Retrofit of steam turbine block (both turbines 8 MW + 20 MW)	4.100.000	34004	47417
Retrofit of steam turbine block (8 MW turbine only)	1.405.714	17786	22174
Retrofit of steam turbine block (20 MW turbine only)	3.514.286	32627	44039

Displayed investments are provided from the consultation with several equipment manufacturers and it is considered to be the market price for the anticipated work. For the assessment of the payback period is also assumed:
– That the loan (which will fully cover this investment) will have 6 years repayment period,
– That the annual interest rate is 7%,
– That the annual price of the equipment maintenance will be 10 €/kW, and
– That the depreciation of turbines and other installed equipment is 15 years.

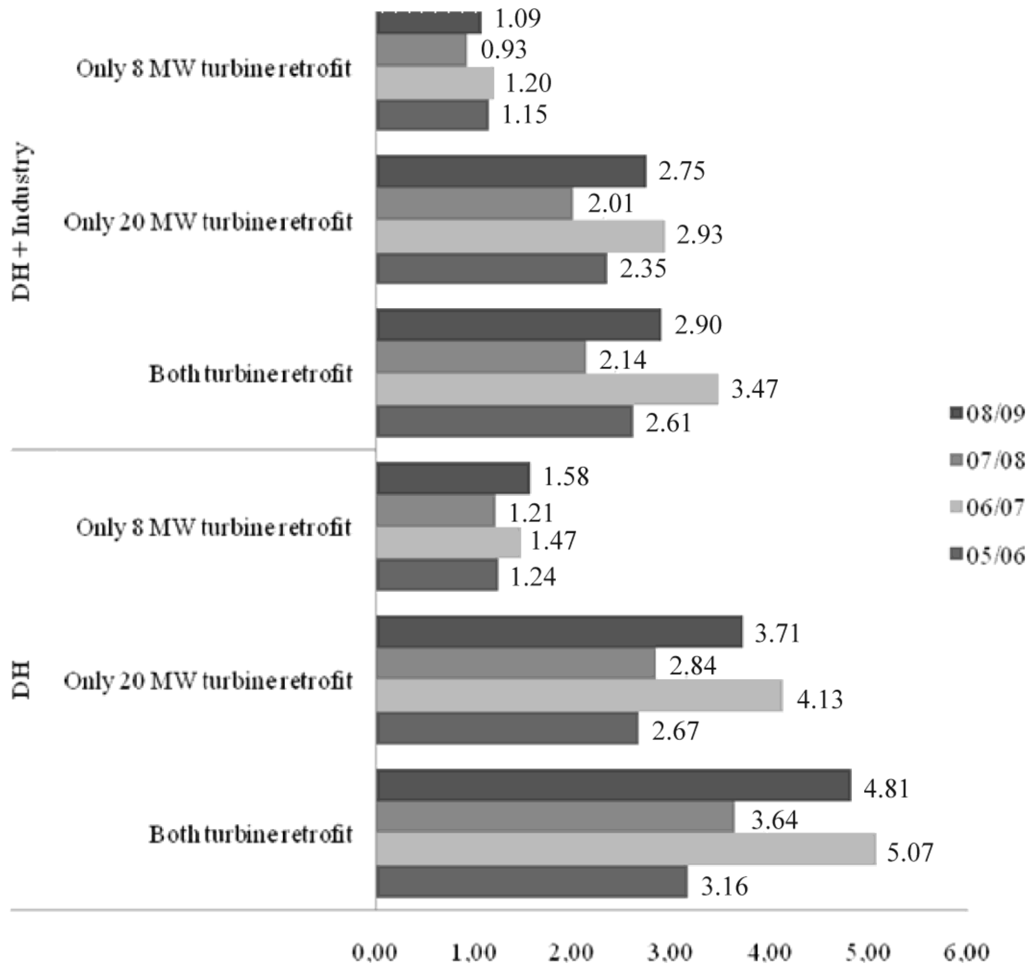


Figure 12. Simple payback period (years) for the input data

Electricity price is defined according to government Directive for feed-in tariffs for period 2010 to 2012 and it is:
– 7.6 c€ per kWh for existing CHP facilities with installed power less than 10 MW (which is used for the case of retrofit of 8 MW turbine only), and

- 4.3 c€ per kWh non feed-in tariff (used for the case of retrofit of 20 MW turbine only and for the retrofit of both turbines).

On the following figure 12, the simple payback periods for all observed cases are shown, and on the figure 13 are shown the IRR and NPV values. Payback periods are estimated according to:

- Heat demand in the season:
  - 2005/2006,
  - 2006/2007,
  - 2007/2008, and
  - 2008/2009.
- The type of the consumers:
  - The DH only, or
  - DH combined with steam and hot water for industry consumers.
- According to one of three possible scenarios of the retrofit:
  - Retrofit of the 8 MW turbine only,
  - Retrofit of the 20 MW turbine only, or
  - Retrofit of both (8 + 20 MW) turbines.

On the following figure 13, the simple payback periods for all observed cases are shown, and the figure 13 are shown the IRR and NPV values for selected scenarios

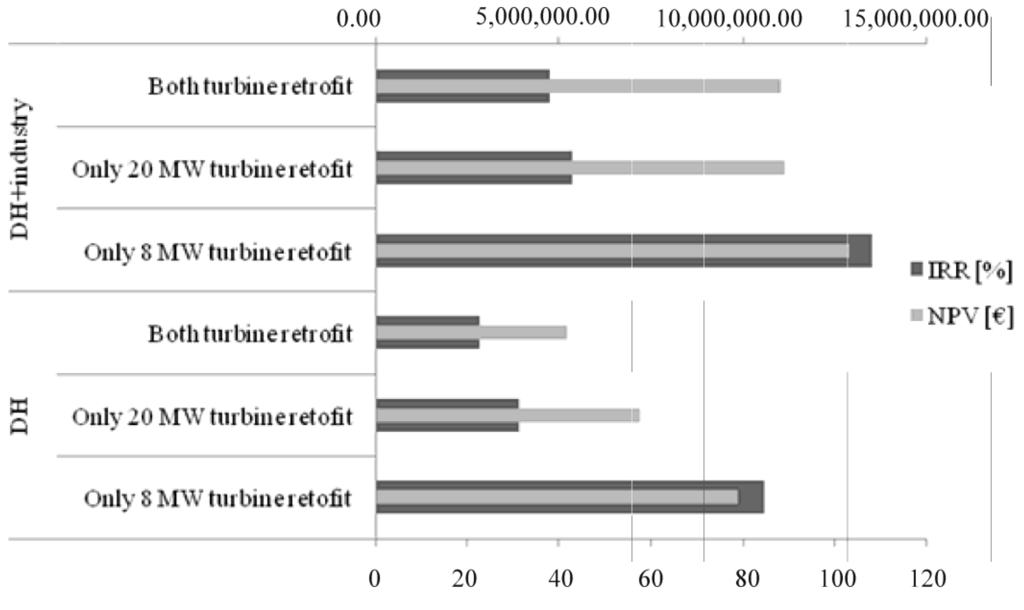


Figure 13. IRR and NPV values for selected scenarios

The picture clearly shows that the most profitable investment option is retrofit of 8 MW turbine. The payback period (approximately one year) is very short. The longest displayed payback period (in the case of investment in retrofit of 20 MW turbine only and in the case of complete withdrawal of the industrial consumers) could be also considered as a short payback period.

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Table 5. IRR and NPV values for selected scenarios

	DH			DH + industry		
	8 MW	20 MW	8 MW	20 MW	8 MW	20 MW
Installed power [MW]	1.405.714	3.514.286	4.100.000	1.405.714	3.514.286	4.100.000
Retrofit investment [€]	1.351.700	1.462.179	1.402.953	1.685.224	1.893.660	2.038.924
Income from electricity production [€]	15	15	15	15	15	15
Depreciation of equipment [year]	10	10	10	10	10	10
Annual costs of the equipment maintenance [€ per kW]	80.000	200.000	280.000	80.000	200.000	280.000
Annual costs of the equipment maintenance [€]	7	7	7	7	7	7
Annual interest rate [%]	6	6	6	6	6	6
Loan repayment period [year]	84,67	31,16	22,6	108,14	43,21	38,03
IRR [%]	9.873.048	7.222.100	5.241.756	12.910.756	11.151.992	11.034.125
NPV [€]	1.405.714	3.514.286	4.100.000	1.405.714	3.514.286	4.100.000

Conclusions

A study has defined:

– Production and consumption of thermal energy at the site "Matična lokacija" in the period 2005-2009,
– Possible scenarios of whether and how reasonable retrofit of the existing steam block is and
– Cost of retrofit,

and proposed:

– Terms and methodology of retrofit, and
– Conceptual design for the retrofit of two existing steam turbines.

All results show that investment in the reconstruction of facilities should be acceptable for the management. Scenarios indicate that in the case of the limited resources (unable to provide a full amount of 4.1 million €) optimal retrofit should start with smaller turbine (8 MW rated power) then after providing the funds should continue with the retrofit of 20 MW turbine.

The best scenario is investment in 8 MW turbine for the following reasons:

– optimal utilization of turbine installed capacity;
– the best price for electricity because of feed-in tariff;
– the smallest investment regarding to other scenarios, and
– IRR for 8 MW turbine (DH only) is 85% (tab. 5).

The analysis focused on current situation (DH is seen as only certain consumer in the future) which is the unfavorable scenario for electricity production. For better utilization of production capacities it should ensure:

– larger demand from the industry;
– demand for thermal energy during summer;
– night demand, and
– attracting new industry and DH consumers in order to increase total demand.

Acknowledgement

This paper is based on a combined heat and power production study conducted for "Energetika" Ltd. from Kragujevac, Serbia.

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Paper submitted: April 15, 2010
Paper revised: May 28, 2010
Paper accepted: June 7, 2010