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Economic evaluation of different-scale gas-steam power plants including costs of decommissioning replaced units

Sebastian Lepszy*, Tadeusz Chmielniak, Daniel Czaja

Silesian University of Technology, Konarskiego 18, 44-100 Gliwice, Poland

Abstract

Interest in natural gas technologies is being driven by twin goals of increasing energy efficiency and reducing power plant emissions, including CO_2. The prospect of shale gas deposits coming online and lowering fuel costs is an added consideration in favor of constructing new gas-steam systems. An important factor affecting profitability is the choice of the power output capacity of the planned units, which naturally impacts initial capital costs. If it is impossible to introduce new units into the power generation system, it is important that the economic analysis should take account of the costs related to early decommissioning of power units. This paper presents an analysis of two gas-steam systems with different power output capacities. The minimum selling prices of electricity are determined. For decommissioned power plants, the conditions (i.e. electricity costs) which make investments in new gas-steam systems equally profitable are defined.

Keywords: Gas-steam systems, Economic analysis

1. Introduction

The reduction in CO_2 emissions related to electricity generation is now a major goal of the power sector. Much research aimed at reducing emissions is concerned with the development of new technologies based on fossil fuels [1] and biomass [2, 3]. Interesting results were obtained in studies on the application of carbon dioxide capture technologies both before [4] and after the combustion process [5, 6]. Replacing hard coal and lignite with natural gas in the process of electricity generation may contribute to a substantial reduction in CO_2 emissions because gas combustion involves lower emissions per unit of energy generated. The use of natural gas as fuel has other advantages too, such as low emissions of nitrogen oxides, dust and sulphur oxides, as well as the possibility of constructing highly efficient electricity generation systems. An essential benefit of gas-based technologies is the possibility of a fast start-up and peak-demand operation. In highly efficient plant, gas-air systems can also be taken into consideration if they have a short start-up time [7]. These advantages become especially important in view of the rapid development of electricity generation based on renewable sources, such as solar and wind power.

The main downside of gas is the high price. There is a chance, however, that gas prices in Poland and all over the world will come down due to the opening up of shale gas deposits.

A number of other factors affecting investments in natural gas technologies could decide about their economic viability. A vital factor is the risk related

*Corresponding author

Email addresses: sebastian.lepszy@polsl.pl (Sebastian Lepszy*), tadeusz.chmielniak@polsl.pl (Tadeusz Chmielniak), daniel.czaja@polsl.pl (Daniel Czaja)

to the instability of legal regulations concerning CO_2 emissions. Other important factors are the stability of prices and the energy security resulting from the use of coal, because coal deposits are rich and spread all over the world [8].

Despite the downsides in the form of the high price and investment risk, gas-based technologies are quite common. Because the energy effectiveness of gas systems is very sensitive to gas prices, it is vital that a thorough economic evaluation is performed. The evaluation often consists in determining economic indices for several solutions which differ from each other in installed capacity. A typical feature of most power plants is that unit investment expenditures fall as the output capacity rises [9]. Hence, high-capacity systems enjoy better economic indices. Another feature related to the scale of the plant is the high electricity generation efficiency of systems with a large power output capacity, which results from the possibility of using more advanced materials and technologies. In this case, an improvement in economic indices can also be observed as the power output capacity rises. Choosing more effective high-capacity solutions may pose a problem with a correct evaluation of economic indices if commissioning new plants involves shutting down older, but still profitable plants. This paper presents a simplified method for calculating economic parameters in this scenario.

2. Analysis of selected solutions

Two gas-steam system solutions were selected for detailed calculations. One is a 32 MW plant with a double-pressure waste heat boiler, the other a 389 MW plant with a triple-pressure waste heat boiler and a steam reheat.

The flowchart of the first gas-steam solution is presented in Fig. 1. The plant under analysis is made of an LM2500 gas turbine with an electric power output capacity of 21.8 MW and a two-casing steam turbine generating electric power of 10.2 MW. The waste heat boiler includes an economizer fed with low-temperature water from the condenser; low-pressure steam is also used in the water deaeration process.

The other system (Fig. 2) is based on a GT26 turbine. It is characterized by high efficiency owing to the use of a high-efficiency gas turbine and an extended waste heat boiler. The basic parameters of the two gas-steam systems are listed in Table 1.

Table 1: Technical parameters of the systems

Parameter	Plant no. 1	Plant no. 2
Electricity generation efficiency, %	52.0	56.8
Net electric power of the system, MW	31.9	389
Gas mass flow, kg/s	1.29	14.4
Gas turbine efficiency, %	35.3	37.8
Net electric power of the gas turbine set, MW	21.7	259
Net electric power of the steam turbine set, MW	10.2	130
Water mass flow in the condenser, kg/s	10.2	94.6
Flue gas mass flow, kg/s	68.8	558

3. Economic analysis

An analysis of the economic effectiveness of the gas-steam power plants was conducted to determine the minimum selling price of electricity, assuming that the net present value $NPV = 0$. NPV is defined as a sum of net money flows discounted separately for each year (CF_t), realized in the entire period covered by the account (from $t = 0$, i.e. from the year of the construction commencement to $t = N$, i.e. the last year under consideration), with a known rate of discount (r). This can be expressed by the following dependence:

$$NPV = \sum_{t=0}^{t=N} \frac{CF_t}{(1+r)^t} \tag{1}$$

Net cash flows (for discount purposes) are determined based on knowledge of: investment expenditures (J), revenues from the sales of electricity (S), operating costs (K_{op}), tax on income (P_d), change in the working capital (K_{obr}), depreciation costs (A), and the value at liquidation—L ($L_t = 0$ for $0 \leq t \leq N-1$):

$$CF_t = \left[-J + S - \left(K_{op} + P_d + K_{obr}\right) + A + L\right]_t \quad (2)$$

Operating costs in (2) are the sum of the following: costs of fuel, costs of servicing, maintenance and routine repairs, costs related to other raw materials, other operating costs (including environmental charges), excise tax and depreciation costs.

Obviously, the revenues from electricity sales and the fuel costs in (2) are related to the volume of electrical energy production and the rate of fuel consumption through the selling price of electricity (C_{el}) and the unit price of the gas fuel. Using Equations (1) and (2), the minimum selling price of electricity was determined:

$$NPV\left(C_{el}^{gr}\right) = 0 \quad (3)$$

A number of assumptions were made for detailed economic calculations. The most important ones are as follows: the time needed for the gas-steam power unit to be constructed—3 years, service life—25 years. The investment expenditures were as follows: PLN 96.3 million—plant no. 1, PLN 830.3 million—plant no. 2 (unit investment cost—€ 725/kWe—plant no. 1, € 513/kWe—plant no. 2); the share of internally generated resources in financing: 20 %, the rest of the expenditures were covered by a commercial loan.

Real interest on the commercial loan was assumed at 7.6%; the loan repayment term: 10 years. The allocation of investment expenditures to be incurred in construction years 1, 2, and 3 was 20%, 40% and 40% respectively. The power plant operating time: 8200 hours per year. Moreover, it was assumed that the average depreciation rate was 9%, excise tax: PLN 20/MWh, income tax rate: 19%. The calculations ignore the change in working capital and the value at liquidation. The price of the gas fuel was PLN 1.29/m_n^3.

The economic analysis gave the following results: the minimum selling price of electricity—PLN 313/MWh and PLN 280/MWh for the first and second system, respectively. The big difference between the minimum selling prices is caused by the large differences in the unit investment expenditures and in electricity generation efficiency between the two systems.

4. Simplifying assumptions and methodology for calculating early decommissioning costs

An algorithm was developed to calculate the costs related to early decommissioning. It is based on the following assumptions.

- the life of each plant in the system is identical—25 years
- all plants in the system are characterized by identical power output, equal to the capacity of plant no. 1
- the power output of the facilities installed in the system under consideration is known and is 798 MW (25*31.92 MW)
- every year power plants are commissioned with a power output capacity equal to the capacity of the decommissioned plants; in the case of plant no. 2, several power units with the total power output similar to the capacity of plant no. 2 are replaced.

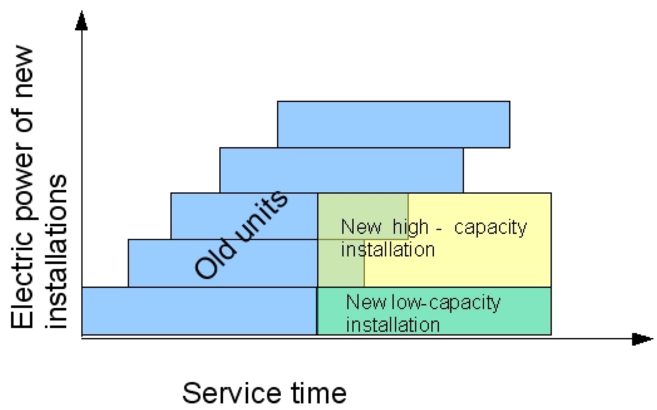

Figure 3: Diagram illustrating the process of commissioning power plants with a high and low power output capacity

The presented model of the system structure is a simplification; only in the case of very big systems can it be considered as close to reality. With detailed data to hand, it is possible to arrange a structure for smaller real systems. Fig. 3 illustrates the idea of operating new power plants with a high and low power output capacity.

Using the above assumptions, it can be determined which power plants will generate electrical energy and for how long. For extreme cases, it is possible to single out the oldest power plant to be decommissioned after its service life expires (the company will suffer no losses if the plant is replaced). The youngest power plant, if decommissioned, causes losses of similar magnitude to the investment expenditures.

Assuming a linear dependence of the cost of electricity generation on the plant age and assuming that the cost of electricity of the oldest plant is equal to the market price, the cost components incurred due to early decommissioning of some power plants can be determined for every year.

In detailed calculations it is assumed that the market price is equal to the cost of electricity generation in the oldest power plant.

In the next step, based on the average operating time of the plants, the amount of generated electricity was determined for every year and for every power plant. The next stage was to calculate the lost cash flows in the case of early decommissioning of a plant. More specifically, the product of the amount of generated electricity ($E_{el\_t\_u}$) and the difference between the market price (C_{el}) and the cost of electricity generation ($C_{el\_K\_U}$) for individual years (t) and expenditures (u) was determined. The lost revenues (CF_L) were calculated for each power plant in individual years using the following formula:

$$CF_L = E_{el\_t\_u} \cdot ((C_{el}) - (C_{el\_K\_u})) \cdot (1 - p_d) \qquad (4)$$

Finally, the obtained values were discounted.

5. Results of the analyses

Summing up the lost and discounted cash flows of decommissioned power plants made it possible to define the dependence of this value as a function of the power output capacity of the power plant replacing decommissioned plants (Fig. 4). The dependence is presented for three levels of the market price of electricity compared to the minimum selling price of a low-capacity plant.

Using the methodology described herein, it is possible to determine, for the assumptions under consideration, the cumulative discounted cash flows related

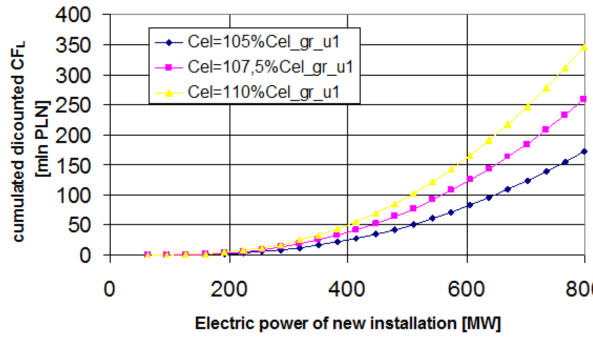

Figure 4: Comparison of cumulative discounted lost cash flows depending on the power output capacity of the new plant subsection

to the loss of revenues in decommissioned power plants if they are replaced with plant no. 2. These are, respectively:

- PLN 23.20 million if the market price is 105% of the minimum selling price for plant no. 1
- PLN 35.19 million if the market price is 107.5% of the minimum selling price for plant no. 1
- PLN 46.41 million if the market price is 110% of the minimum selling price for plant no. 1

Table 2: Market price and the minimum selling price of electricity for plant no. 2

	C_{el}, PLN/MWh	$C^{gr}_{el\_u2}$, PLN/MWh
$C_{el} = 105\% C^{gr}_{el\_u1}$	330	281
$C_{el} = 107.5\% C^{gr}_{el\_u1}$	337	281
$C_{el} = 110\% C^{gr}_{el\_u1}$	345	282

Using these values, the selling prices of electricity were corrected. The results are presented in Table 2. An analysis of these results indicates that due to the very high efficiency of plant no. 2, the level of the minimum selling price rises only slightly if decommissioning costs are taken into account.

Another result of the analysis was the determination of the electricity market price level for which the economic effectiveness of plant no. 2, expressed by means of the minimum selling price, would be equal to the minimum selling price for plant no. 1. The calculations gave a very high value of the market price of PLN 926/MWh (296% of the minimum selling price for plant no. 1).

The unit investment expenditures are the main element, apart from technical issues, determining the high economic effectiveness of plant no. 2. Its impact on the possibility of reaching a similar economic effectiveness was defined by determining unit investment expenditures that guaranteed obtaining the minimum selling price identical to that in plant no. 1. The value of the unit investment expenditures should then be € 1069/kWe (which is more than the unit expenditures for plant no. 1).

6. Conclusions

The presented calculation algorithm enables an approximate determination to be made of the economic effects of an investment which involves early decommissioning of power plants which are still economically effective.

The economic parameters obtained, as well as the levels of prices, differ substantially from present values due to the fact that the considerations were limited to a system with gas-steam plants only; no support in the form of certificates obtained for electricity generation from gas, for example, was taken into account.

Due to the assumptions adopted, some of the results obtained should in great measure be evaluated qualitatively rather than quantitatively.

The results indicate that based on the average level of parameters characteristic of gas-steam systems, power plants with a large power output capacity are much more effective than small-scale plants, even if the revenues lost due to early decommissioning of some power plants are taken into account.

Should the construction of a high-capacity gas-steam system prove too costly, i.e., should it be characterized by high unit investment expenditures, the economic effectiveness of the large- and small-scale plant might still be similar. For the assumed values of parameters such a situation occurs if the unit investment expenditures for plant no. 2 exceed 147% of the unit investment expenditures for plant no. 1.

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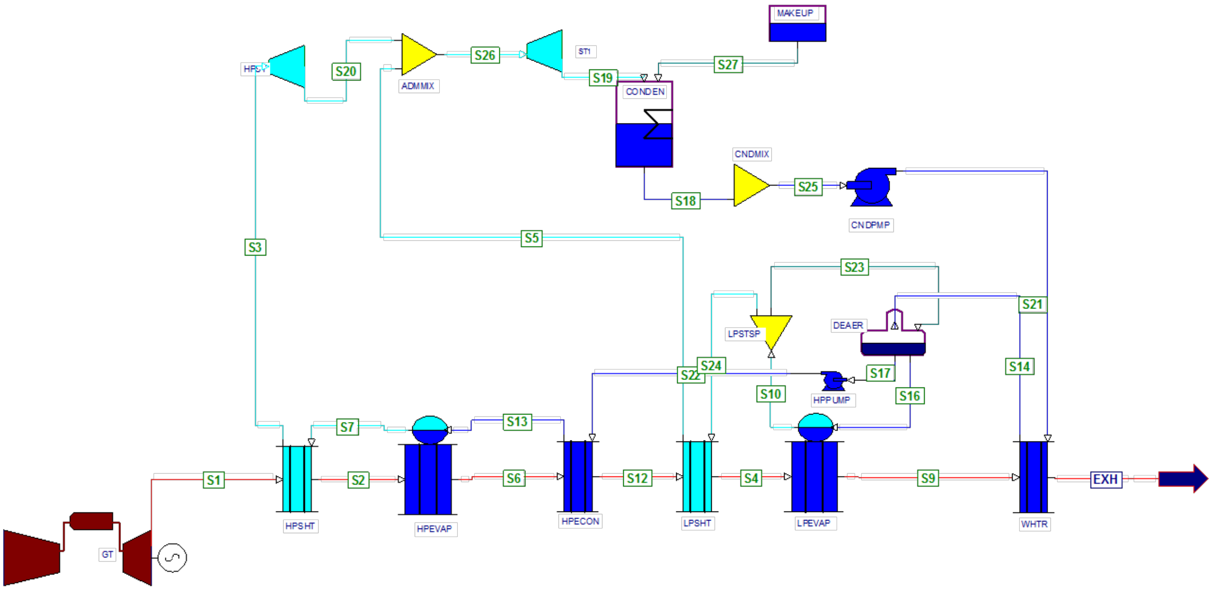

Figure 1: Flowchart of a low-capacity gas-steam system (plant no. 1)

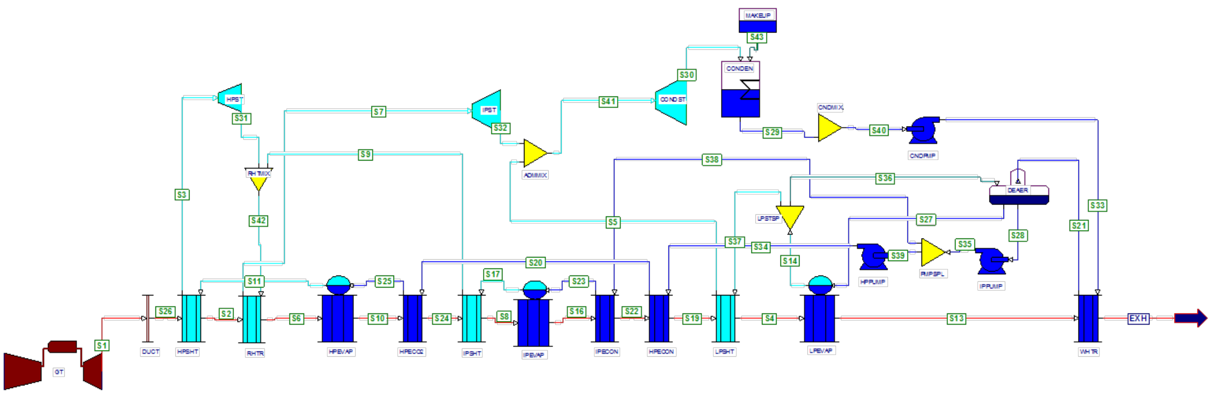

Figure 2: Flowchart of a high-capacity gas-steam system (plant no. 2)