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Economical analysis of energy conversion and use by cogeneration systems with microturbines

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Abstract: - The object of the analysis is energy supply systems with microturbines. The first goal of the presented paper is to apply different economical methods of evaluating the cogeneration systems with microturbines. Four methods and parameters were analysed: NPV (Net Present Value), NPVR (Net Present Value Ratio), IRR (Internal Rate of Return) and (Discounted Pay Back). It was investigated, which method and which parameter is most suitable to evaluate the energy conversion and use in the relevant installations.

In order to show a practical use a representative technical project was taken into consideration and analysed. It is an installation with heating, cooling and power application (swimming pool and restaurant). Typical system with microturbine and waste heat utilisation is combined with absorption refrigerating machine. The knowledge and conclusions from the first part served as evaluation of a specific technical solution.

The discussion of results should point out some more general conclusions and regularities for using microturbines in energy supply installations. After the economical point of view had been coupled with the efficiency of energy transformation the analysis became complete and took under consideration its most important aspects.

Key-Words: - Microturbines, Cogeneration, Energy Supply Systems, Efficiency, Economical Analysis

1 Introduction

The advantages of micro gas turbines induce increasing interest in using them in cogeneration energy supply systems, that is for heat and electricity production. The mentioned technical solutions are efficient, environment friendly, compact, reliable and available for efficient complex solutions. Typical applications of microturbine cogeneration systems include heating and cooking in hotels, public buildings, swimming pools, etc. [5,6,7,8].

Intensive engineering development in this area in the last decades contributed to technical progress and the possibilities of system optimisation. On the other hand, the economic parameters and frame conditions determine the applications in practice [1,2]. That is why the main aim of the following analysis is to investigate the influence of different parameters on the economic effect in connection with the efficiency of energy use.

A representative project constituted the basis for the practical application of the calculations method.

2 Analysis of a Representative Cogeneration Energy Supply System with Microturbine

The technical and economical analysis of cogeneration systems with microturbines results from the respective technical project (fig.3). This is the energy supply system which can be used in objects with swimming pools and restaurants for heating, cooling and power application. The graph shown in figure 1. illustrates the yearly thermal and electrical requirement of a model object.

Unlike the thermal and electrical requirement, the energy requirement for cooling is not continuous and amounts to 15 - 40 kW in the transitional season and 60 kW during the summertime (in winter 0 kW).

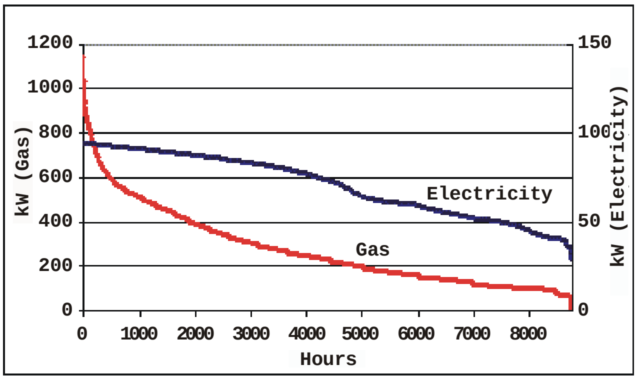

Fig. 1 Thermal and electrical energy requirement of the relevant object

Figure 2 illustrates one of the most important advantages of the cogeneration systems with microturbines which is the relatively constant efficiency by varying load. That is the reason, why the impact of the variable load on the turbine and generator efficiency was not considered in the following calculations (the average values were representative for the analysis).

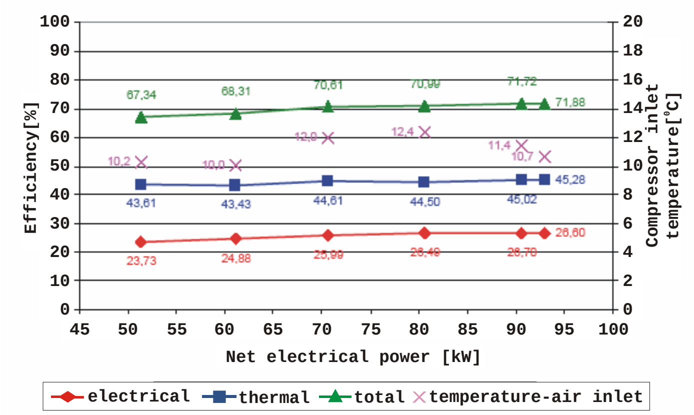

Fig.2 Part-load effect on electrical and system efficiency

Figure 3 shows the relevant installation with microturbine (Capstone C30), waste heat utilisation, absorption refrigerating machine (AKM York WFC 10) and gas boiler. Additionally, the most important thermodynamic parameters of the system (temperature, pressure, enthalpy and mass flow rate) were written down. In this case transitional season served as an example for possible operating conditions. Similar calculations were made for summer and winter seasons. The most important differences between the three operating states can be recapitulated to the following points:

- no cooling requirement in winter,
- constant cooling capacity during the summer period, that is 40 kW continuously 8 hours per day,
- variable cooling requirement during the transitional season from 15 to 40 kW 8 hours per day.

The particularised data and results of the thermodynamic and energetic calculations are not the main matter of the publication. They should only serve as the basis for some general conclusions.

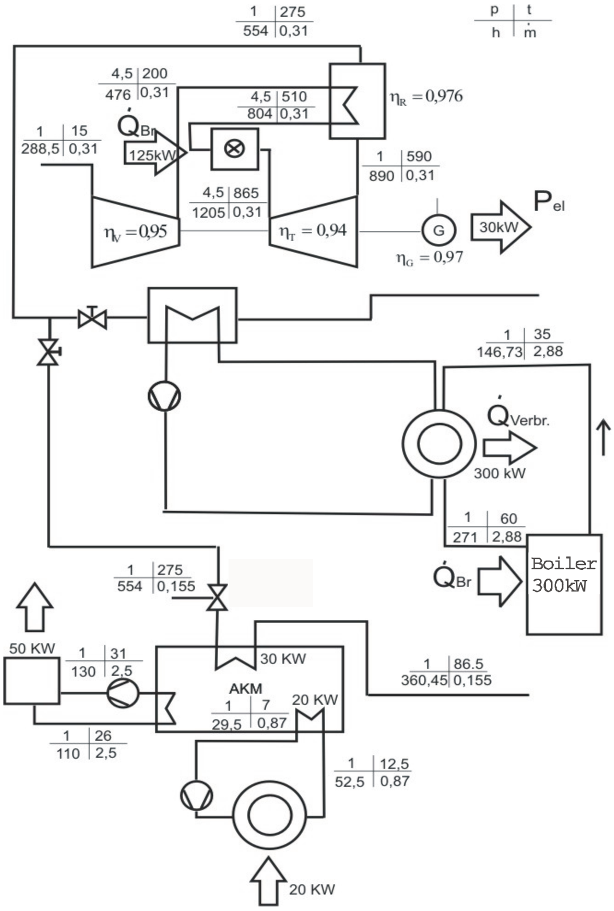

Fig.3 Cogeneration energy supply system with microturbine - thermodynamic parameter (calculations by nominal capacity for transitional season).

3 Parameter for Economical Evaluation

The conventional economical methods can be modified and applied to evaluation of heat-, cold- and electricity-production in cogeneration systems. Most precise and realistic are dynamic procedures based on discounting calculations.

There are two most important parameters and methods, which can also be used by energy production related problems:

- NPV (Net Present Value),
- IRR (Internal Rate of Return).

The first method (NPV) makes it possible to evaluate the present value of earnings and expenditures connected to the relevant project. This can be presented mathematically by the general equation:

$$NPV = CF_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \Lambda + \frac{CF_n}{(1+r)^n} = \sum_{i=0}^{n} \frac{CF_i}{(1+r)^i} \qquad (1)$$

where:
CF_0 - amount of investment costs connected with the relevant project,
CF_i - cash flow connected with the project in the current year "i",
r - discounting rate.

The objective function applies to maximum NPV value.

The method of internal rate of return (IRR) defines the interest rate, which would be the consequence of NPV = 0, that is:

$$CF_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \Lambda + \frac{CF_n}{(1+r)^n} = 0 \qquad (2)$$

Additionally, the Net Present Value Ratio (NPVR) can be considered, if the optimal option has to be selected from several variants.

$$NPVR = \frac{NPV}{J_0} \qquad (3)$$

where:
J_0 - investment capital.

Discounted Pay Back Period (DPBP) is the minimal number of "n" resulting from the following equation:

$$\sum_{i=0}^{DPB} \frac{CF_i}{(1+r)^i} = \sum_{i=1}^{DPB} \frac{CF_i}{(1+r)^i} - J_0 = 0 \qquad (4)$$

It is the minimal period of time, when the amount of discounted cash flows equals null [3].

The following analysis is based, first of all, on the net present value method.

4 Economical Analysis

After evaluating the thermodynamic calculations and efficiency analysis the economical aspects were investigated. The principal aim of this investigation was the decision, whether the integration of cooling system (with the absorption refrigeration machine) can improve the co-generation system's effectiveness from the economical point of view. The following are vital basic data assumed for the calculations (Table 1).

Table 1 Basic data for the economical calculations

Cogeneration System: Heating and Power		
Fuel Input	125 kW	
Electrical Output	30 kW	
Thermal Output	60 kW	
Electrical Efficiency	0,24	
System Efficiency	0,72	
Full load hours	8000 h	
Electricity price	0,13 €/kWh	
Investment costs (micro turbine)	45 000 €	
Gas price	0,033 €/kWh	
Running time	10 a	
Interest rate	6 %	
Cogeneration System: Heating, Cooling and Power (additional data)		
Cooling requirement / total operating period	15 kW	250 h
	20 kW	240 h
	30 kW	490 h
	40 kW	250 h
Cooling energy price	0,081 €/kWh	
Investment costs (absorption cooling machine)	25 000 €	

Based on the above-mentioned frame conditions the relevant economical parameters were calculated. They are [4]:

- annuity:

$$a = \frac{q^n \cdot (q-1)}{q^n - 1} \qquad (5)$$

- net debt value:

$$k_D = I_0 \cdot a \qquad (6)$$

- dynamic payback period:

$$t_A = \frac{\ln\left(1 - \frac{I_0 \cdot (q-1)}{R}\right)}{\ln\left(\frac{1}{q}\right)} \qquad (7)$$

- capital value:

$$C = R \cdot \frac{q^n - 1}{(q-1) \cdot q^n} \qquad (8)$$

where:
q - calculation's interest rate,
I_0 - investment costs,
R - (constant) difference of annual earnings and expenditures.

5 Relevant Calculations Results

The most important results of economical analysis are the dynamic pay back period and capital value after 10 years (assumed depreciation period). These results and additionally the annuity and net debt value are compiled for two options (table 2):

- option A: cogeneration system with heating and power application,
- option B: heating, cooling and power application.

Table 2 The relevant results of the economical calculations

Option:	A	B
Annuity a	0,136	0,136
Net debt value k_D [€]	6115	9513
Payback period t_A [a]	3,56	5,82
Capital value C^* [€]	106 000	107 500
Yearly balance [€/a]	8280	5080

$^{*)}$ after 10 years

6 Conclusion

The cogeneration systems with microturbines enables the fuel to be used effectively from the thermodynamic and economic point of view. The efficiency resulting from using these systems and energy conversion is also coupled with technical advantages (operation, maintenance) and environment friendly aspects.

Above all, the economic parameters and frame conditions determine the applications in practice. That is why a representative project was investigated in order to show the economical aspects on the basis of thermodynamic analysis. The results from the analysed example are generally positive which means the cost-effectiveness has been proved. The comparative investigation shows, that the installation's extension by cooling system is not efficient. Although both of the options (with and without cooling) are cost effective the option without cooling is, by all means, more profitable. Certainly, it is not the only conclusion connected to the cogeneration systems with heating and cooling and results from the frame conditions of the investigated application.

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