ARCHIWUM ENERGETYKI tom **XLII**(2012), nr 1, 69–79

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Use of gas in distributed sources in extensive heating systems

The aim of an investigation was to examine the heat sources, which can be used as a supplement for providing the heat for the users at the ends of extensive heating networks. The research was based on the technical and economic analysis that also included ecological effects. The integral element of the research was a comparative analysis of such distributed heat sources and the current heating systems regarding their mutual competitiveness factors or supplementation.

1 Description of distributed sources conception in heat engineering

Electricity distributed generation is widely known [1]. It is currently popular and broadly discussed topic. Heat networks operate on quite similar principles as electric grids. Obviously, the scale and range of heat networks is much smaller than that of electric grids. The idea for large heating system is that many buildings are fed from the radial-annular network. The network is fed by the central source (or more than one source). In Poland, in case of more than one central source, the sources operate most frequently for so-called allocated heat supply areas.

The aim of this investigation was to examine economic feasibility of constructing distributed heat sources and/or small gas cogeneration sources cooperating with extensive heating systems. The paper presents alternative connection methods for the users at the ends of heating network. It often happens that this type of reception is accompanied by power shortage (not the heat) resulting from the

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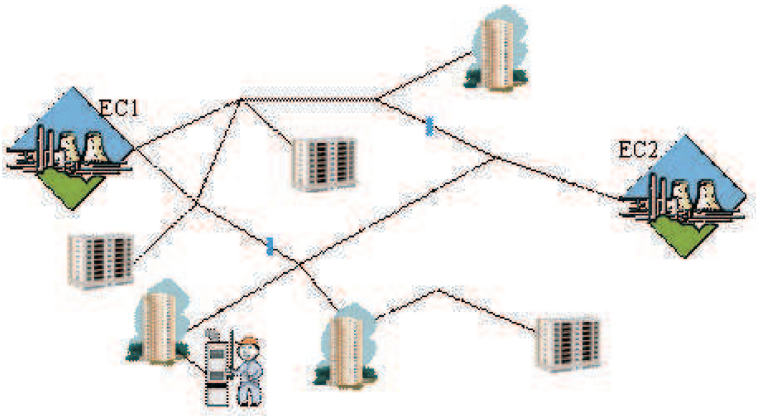

Figure 1. Exemplary scheme of a heating system with a distributed heat source with two combined heat and power (CHP) installations.

network hydraulic limitations. This fact implies significant investments in development of heating network in order to eliminate the limitations. The alternative is to additionally supply such recipients from the distributed heat sources as shown in Fig. 1. It means that the recipient may be supplied with heat from own source and from the heating network. The way of cooperation between the distributed source and heating network may differ greatly. Various variants of cooperation between the source and heating network securing the supply for the recipient and electricity generation will be presented in following parts of the paper.

2 Analysis and variant selection of distributed heat sources for application in extensive heating networks

In order to select the sources for distributed heat generation it is necessary to determine the significant features, which these sources should possess. On that account, the sources for distributed generation should:

- secure the possibility of remote control – personnel costs minimisation,
- be ‘environment friendly’ – proximity to residential buildings.

The condition of being environment friendly is fulfilled by the sources fed oil and gas. Realisation of environment friendly sources in coal technology is very difficult and expensive, if not impossible. Additionally, maintenance-free work in coal sources is practically impossible. Taking into account the gas and oil prices, it has been decided to analyse further only natural gas.

The possibility of employing various kinds of sources in distributed power systems is widely discussed. One of such possibilities are fuel cells [2,3]. Unfortunately, they have not yet widely applied. Currently the commonly used sources, which are fed by natural gas, are:

- water boilers – only heat supply,
- piston engines – heat and electricity,
- gas turbines – heat and electricity.

Using gas water boilers as a local distributed source is a real possibility. If one compares the proposed cogeneration sources, taking into account the fact that the analysis is pertained to small heat sources, the practice shows that piston engines are better suited for these types of sources, than gas turbines. It stems from better economic efficiency of piston engines. The additional argument for piston engines is a much higher noise level generated by gas turbines, which is quite significant in case of distributed sources.

Natural gas prices are regulated by the tariffs. The law imposes the necessity of dividing the prices and rates into permanent and changeable rates. On that account, the gas price depends on the time of peak power usage and the tariff group. In order to depict the differences, the variability of the average price of chemical energy contained in the fuel depending on the chosen tariff groups and the time of peak power usage are presented in Tab. 1. The majority of calculations are made for tariff rates W6A [4]. This tariff is for the order of gas energy in the range between 65 and 600 m^3/h. It gives, with the lower heating value of 36 $\mathrm{MJ/m}^3$, the range of power in the fuel from 650 to 6000 kW.

3 Heat supply variants

It is assumed that the recipient may be supplied from a distributed source (piston engine or gas boiler) and/or from the heat network. The base demand may be satisfied by the peak source or by the heat network. In result, five variants for recipient supply were defined. Summary comparison of the variants is given in Tab. 2. It is assumed that the total heat demand of a recipient amounts to 1 MW. On that account, the way of meeting the heat demand by the network and distributed source was determined. The results are given in the diagrams 2–6. The summary values comparison is given in Tab. 3.

Table 1. The unit cost of chemical energy in gas fuels in PLN/GJ for gas GZ-50 [MJ/m^3].

Contracted power	Time of peak power usage								
	500	1000	2000	3000	4000	5007	6000	7000	8000
200	64.66	48.15	39.89	37.14	35.76	34.23	33.70	33.31	33.02
300	64.50	48.06	39.85	37.11	35.74	34.21	33.68	33.30	33.01
400	64.41	48.02	39.83	37.10	35.73	34.21	33.68	33.29	33.01
500	64.36	48.00	39.81	37.09	35.72	34.20	33.67	33.29	33.00
598	64.33	47.98	39.81	37.08	35.72	34.20	33.67	33.29	33.00
602	61.11	45.64	37.91	35.34	34.05	32.61	32.11	31.74	31.47
650	61.08	45.63	37.91	35.33	34.05	32.60	32.10	31.74	31.47
700	61.06	45.62	37.90	35.33	34.04	32.60	32.10	31.74	31.47

Table 2. Comparison of basic features of particular variants.

No.	Variant's symbol	Basic source description	Peak source description
1	HN	The whole supply comes from the heat network	None
2	HN-GB	The heat network is the major supplier (40% of power)	60% of the ordered power is supplied from the peak boiler
3	GB-HN	The base heat demand is met from the gas boiler (40% of power)	Peak demand is met from the heat network
4	GE-HN	The base heat demand is met from the gas engine (18% of power)	Peak demand is met from the heat network
5	GE-GB	The base heat demand is met from the gas engine (18% of power)	Peak demand is met from the gas boiler

Table 3. Comparison of heat amount supplied by the particular sources in particular variants in GJ.

	Heat network	Gas engine	Gas boiler	Sum
HN	10877	0	0	10877
HN-GB	8271	2606	0	10877
GB-HN	0	2366	8511	10877
GE-HN	6310	4567	0	10877
GE-GB	0	4567	6310	10877

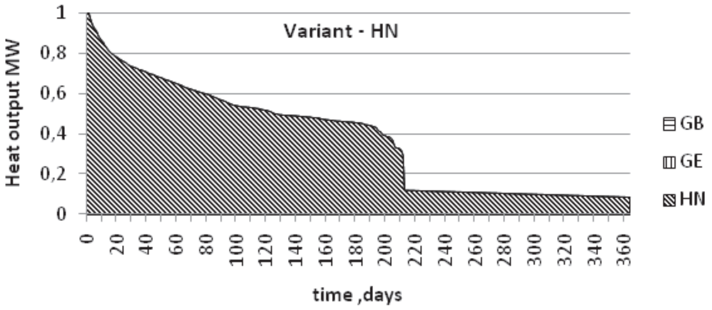

Figure 2. Systematic diagram – the structure of meeting the recipient demand for the variant HN (HN – heating network, GE – gas engine, GB – gas boiler).

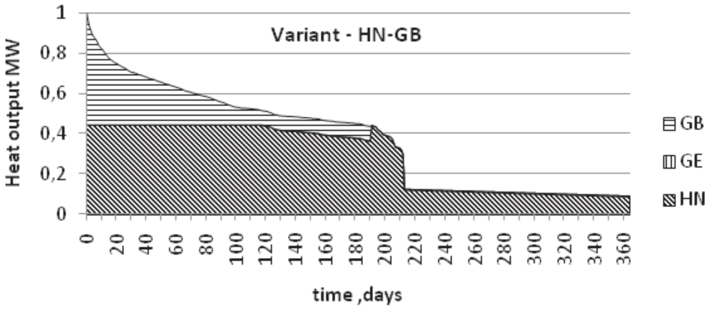

Figure 3. Systematic diagram – the structure of meeting the recipient demand for the variant HN-GB (HN – heating network, GE – gas engine, GB – gas boiler).

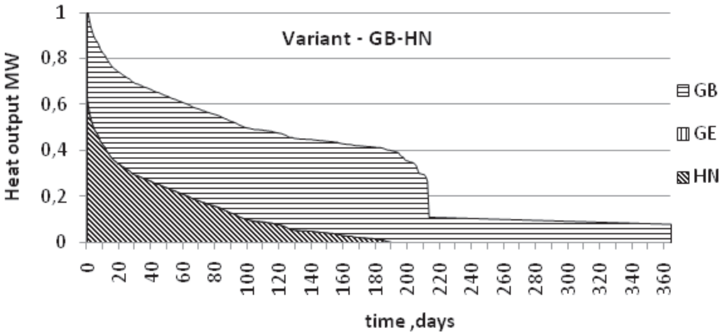

Figure 4. Systematic diagram – the structure of meeting the recipient demand for the variant GB-HN (HN – heating network, GE – gas engine, GB – gas boiler).

4 Central source operational model

The systematic diagram of the operation of a central source was drawn basing on real data from several Polish plants. It was assumed that the unit has 100 MW

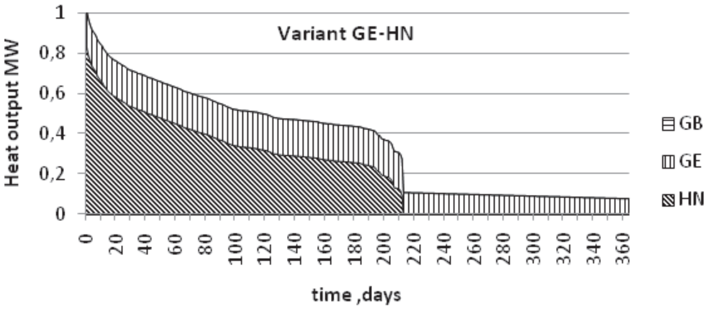

Figure 5. Systematic diagram – the structure of meeting the recipient demand for the variant GE-HN (HN – heating network, GE – gas engine, GB – gas boiler).

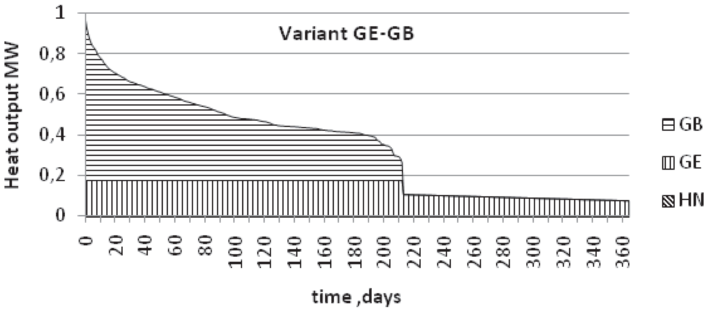

Figure 6. Systematic diagram – the structure of meeting the recipient demand for the variant GE-GB (HN – heating network, GE – gas engine, GB – gas boiler).

of power and that 60% of power is produced in cogeneration and 40% of peak power units (water boilers). The modelled demand for heating power from the central unit was presented in Fig. 7. Moreover, it was assumed that the source was fed with hard coal as most of combined heat and power (CHP) plants of the type.

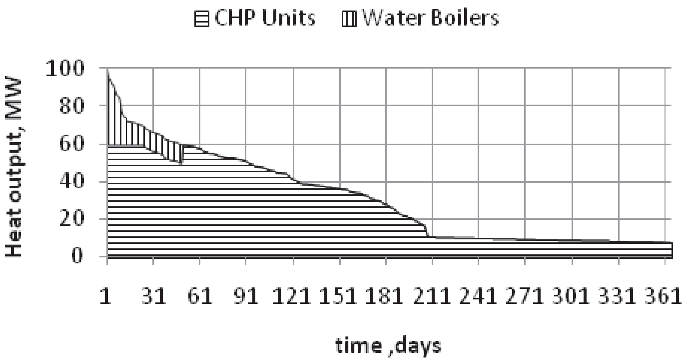

Figure 7. Example of load distribution on generating units.

5 Technical and economic analysis

5.1 General assumptions

The aim of the analysis is to determine whether application of changes proposed will lead to decrease of heat generation costs and, therefore, minimize the price of heat for end-users. The owners of the heat source and of the heating network may have the same owner or different ones. It was assumed that the owner of both the network and the source is one business entity. If, in such case, it will be possible to obtain profitability of the project, it will also be valid for separate ownership of the network and the source. The two owners will then divide the costs and profits and the project will decrease costs of heat for the end-users.

In the stage of calculations it was assumed that 100% of funding was made from own capital. Another significant assumption is that construction of distributed sources will not cause the need to reduce the capital in the central source. Owing that it was assumed that fixed costs of generation will not be reduced. Only the variable costs will be limited and they were defined as 5% of fuel costs.

5.2 Investment outlays

Each variant includes different investment outlays. The description of the investment that has to be made in case of all the variants was presented in Tab. 4. Values of the outlays for each variant were presented in detail in Tab. 5.

Table 4. Necessary investment for each variant for distributed and central sources by type.

Variant	Construction of a gas connection for peak and base units	
	Base source	Peak source
HN	Connection to the building, construction of heating substation. Power of the connection and substation 1 MW	None
HN-GB	Connection to the building, construction of heating substation. Power of the connection and substation 400 kW	Construction of a boiler house and gas connection of power 600 kW
GB-HN	Construction of a gas boiler house of power 400 kW and gas connection	Connection to the building, construction of heating substation. Power of the connection and substation 600 kW
GE-HN	Construction of a cogeneration plant of power 180 kW and gas connection	Connection to the building, construction of heating substation. Power of the connection and substation 820 kW
GE-GB	Construction of a cogeneration plant of heating power 180 kW	Construction of a boiler house of power 600 kW

Table 5. Investment needed in thousands of PLN.

Variant	Heating network	Gas-supply network	Gas boiler	Piston engine	Heating substation	Total
HN	186	0	0	0	1350	1536
HN-GB	165	86	900	0	540	1691
GB-HN	172	82	600	0	810	1664
GE-HN	180	78	0	810	1107	2175
GE-GB	0	93	1230	810	0	2133

5.2.1 Costs and operational revenues

In order to determine the cash flows it is necessary to determine costs and operational revenues. Operational costs include:

- change of fuel consumption in the CHP plant,
- fuel consumption in the distributed source,
- maintenance and service costs for:
  - heating substation and boiler in the amount of 2% of yearly investment outlays,
  - gas engine in the amount of 5% of yearly investment outlays,

- change of CO_2 emission costs including:
    - change of CO_2 emissions in the CHP plant,
    - free-of-charge CO_2 allowances for heat and electricity generation,
    - emission of CO_2 from distributed source.

The revenues include the following:

- change in electricity generation,
- change of revenues resulting from red certificates trade,
- change of revenues resulting from yellow certificates trade.

5.2.2 Heat and electricity prices forecast

All the calculations were made for fixed prices. The only variations were considered for electricity and heat prices. Own forecasts were made for the purpose. The assumptions are based on the fact that electricity prices will be formed by the utility power plants and the heat prices by the heating stations. Another assumptions is that power plants will transfer 100% of allowances costs into electricity price and that heat plants will transfer 100% of allowances costs into heat price. Allowances costs include free-of-charge allowances for electricity and heat generation. Assuming fixed CO_2 emission allowances price at 15 EUR/Mg and that 100% of the costs will be transferred into heat and electricity generation, forecasts for electricity and heat prices were made and are presented in Fig. 8. In case of heat prices the 'gas benchmark' for free-of-charge allowances was included.

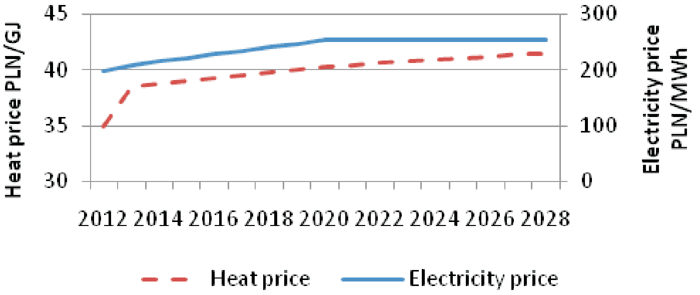

Figure 8. Electricity and heat price forecast for calculations.

5.2.3 Economic analysis

In order to compare all the variants the internal rate of return (IRR) value was chosen because it does not require defining the rate of discount [5]. The main disadvantage of the IRR value is that the cash flow can have only one change of sign (in other case the IRR value is not unambiguous). In the analysis values of different initial outlays will be compared. In order to determine the IRR, values of cash-flow in each year were determined. The results are presented in Tab. 6.

Table 6. Results of economic analysis.

Variant	HN	HN-GB	GB-HN	GE-HN	GE-GB
IRR [%]	13	-1	–	10	-2

From the presented variants it is conspicuous that the most profitable case is heating from a large CHP plant through a heating network. The second most profitable is base heating by a gas engine and peak heating by heating network. The variant, in which the base demand is covered by the heating network and only peak load is covered by a gas boiler is not profitable. Similarly not profitable is the case when the base demand is covered by a gas boiler and the peak one by the heat from the heating network.

6 Summary

The idea of supplying heat from the heating network and an additional heat or heat and power source in different configurations was presented in the paper. From the presented calculations it stems that the most attractive way is to supply the heat only from the heating network. The alternative using distributed source is application of a gas engine as the base source and the heating network as a peak one. Specific conditions like length of the gas connection to the connection to the heating network will influence the profitability of the project.

We also have to consider that application of distributed sources may significantly increase reliability of supplying the end-users. Currently the topic of supplying standards and the security of heat supplies is neglected but the safety of constant supply is a product and may be evaluated. Revenues from the reliability of supplies may increase the profitability of such solutions. Common use of such applications may also decrease the costs of modernization and development of heating network which may also increase the effectiveness of the solution.

The paper focuses only on the technical and economic analysis of supplying heat from distributed sources. It had the aim to determine the purposefulness of using distributed sources in heating systems. The next step should involve technical possibilities of cooperation of distributed heat sources with the heating network.

Acknowledgments This study was sponsored by the Polish Ministry of Science and Higher Education in the period 2010–2011.

Received in June 2012

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Wykorzystanie gazu w źródłach rozproszonych w dużych systemach ciepłowniczych

Streszczenie

W pracy zaprezentowano rozważania dotyczące ekonomicznej celowości instalacji zastosowania źródeł rozproszonych w ciepłownictwie. Pomysł zastosowania źródeł rozproszonych w ciepłownictwie podobny jest do tego obecnie szeroko dyskutowanego pomysłu źródeł rozproszonych do produkcji energii elektrycznej. Ze względu na obecne warunki ekonomiczne do rozważań wybrano źródła zasilane gazem ziemnym. Zaproponowano pięć sposób zasilania odbiorców na końcach rozległych sieci ciepłowniczych. Dla przedstawionych wariantów wykonano analizy ekonomiczne, których wyniki przedstawiona w pracy.