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Energy and economic optimization of the repowering of coal-fired municipal district heating source by a gas turbine

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A B S T R A C T

One of the possible solution for conventional coal-fired heat sources of district heating systems is repowering with a cogeneration of heat and power) unit. Thermal and economic optimization of the such modernization is the subject of the paper. The total capacity of the existing heat generating plant reaches 210 MW and the generated heat is delivered to the city consuming central heating and hot domestic water. The optimization of the cogeneration system (regarding unit size) was aimed at finding a solution which is an optimal in terms of the economic efficiency.

The optimal size of gas turbine was found and it has been proven that the retrofitting coal-fired district heating source with a gas turbine cogeneration unit has technical and economic justification and always leads to the energetic and ecological effects. However, the optimal size of the unit is highly sensitive to electricity and natural gas prices.

1. Introduction

Demand for clean environment as well as limited resources of fossil fuels create a major push to resolve on-going issues of creating energy technologies that lead to sustainable development [1]. These technologies should be highly efficient, effective and environmentally friendly. Many countries have adopted energy policies that assume an increasing share of renewable resources in final energy generation as well as increasing share of more efficient technologies such as cogeneration of heat and power (CHP).

The fact is, that solid fuels, mainly coal, still continue to dominate in the structure of the electricity and heat production system in certain countries of the world, including countries in Europe. As for heat, it can be generated in a distributed and individual sources as well as in a large-scale, mainly high-temperature centralized district heating (DH) systems.

According to [2] DH technologies are divided into CHP and heating-only technologies. The aforementioned systems can be additionally extended by cooling systems, whose notability remains arising [3] and are proven to be economically feasible [4]. As stated in [5] trigeneration (or CCHP) is even one step ahead of cogeneration, referring to the simultaneous generation of electricity, useful heating, and cooling from a single fuel source. District heating systems enable the use of a variety of heat sources: from conventional, coal-fired plant, that are often wasted, to the installations generating the renewable heat. Thorton and Monroy have investigated the current state of application for each of the DH system in the United States, pointing out that the wide implementation of the renewable heat sources are mainly limited by legal regulations [6]. Vallios et al. have proposed the methodology for predicting the effects of extending DH with biomass heating in terms of economy and thermodynamics [7]. According to Heidenreich and Foscolo, biomass gasification is the most promising technology for the utilization of such a fuel, especially for district heating [8]. It is important to point out that DH systems can also use different energy sources in a common cycle, creating hybrid systems, which gives a significant technological advantage and the potentials of further development, as presented in [9]. These hybrid systems combine conventional methods of energy production from fossil fuels, with the use of alternative and RE technologies, like heat pumps, solar collectors or gasification of fuels (coal, biomass) and wastes, including municipal solid wastes with great potential for heat recovery in district heating systems [10]. In the

Abbreviations: CB, coal-fired water boiler; CCHP, combined cooling, heating, and power; CHP, cogeneration of heat and power; DH, district heating; GB, gas boiler; HRB, heat recovery boiler; IRR, Internal Rate of Return; NPV, Net Present Value; WP, pulverized-coal water boiler; WR, stoker-fired water boiler.

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work undertaken by Levihn CHP plant with combination of large scale heat pumps are considered to balance energy production from renewable sources, based on the example of Stockholm city [11].

The integration of renewable energy sources in district heating systems is important goal that needs to be achieved [12], however there are still much to do regarding improvements in the field of retrofitting heat generating infrastructure with more efficient technologies. The transition from conventional energy technologies to combined DH systems, including conventional heating systems repowered with cogeneration units fed with natural gas, is already noticeable in Europe. Gimelli et al. have analyzed the possibility of application CHP gas engines for chosen Italian hospitals [13].

Nowadays, the trend to improve the district heating systems is spreading all over Europe, such as the Heat Roadmap Europe project and the STRATEGO project (Enhanced Heating and Cooling Plans in EU) [14]. As presented in [15] the integration of district heating in future sustainable cities is expected with special emphasis on the wide use of combined heat and power together with the utilisation of heat from waste-to-energy and various industrial surplus heat sources as well as the inclusion of geothermal and solar thermal heat. Moreover, according to [16] most of the European cities aim to realize a citywide integrated district heating and cooling system in the near future. The importance of district heating has been increasing with the growing penetration of intermittent renewable in energy systems across Europe, as stated in [17].

According to [18], there has been more than 4.100 DH systems in Europe, while the energy market share of DH systems corresponded to 10% of the heating market in Europe in 2011 year. Central and eastern EU regions are characterized by a high contribution of DH applications in supplying with heat residential buildings, mainly in large urban areas with large reserves of local coal for heating, compared to other EU regions where the dominant energy source is gas and fuel oil with addition on renewable energy resources. District heating system supply with heat around 29% of residential buildings in Central and East Europe, while in case of North and West Europe countries this share is reduced to only 6% [19].

An interesting example is Poland with 41% participation of DH system [20] and in the same time with coal as a main source of input energy of heat generating plants. Compared to other European countries, particularly these located in western and northern part of Europe, where district heating system is more supplied with natural gas or renewable sources (Fig. 1), a polish case is worth attention. The structure of the DH fuels consumption in Poland over the past ten years has remained stable. Similar to 2004, the dominant fuel is hard coal whose share has not significantly changed over this period: from 77.8% in 2004 to about 74% in 2011 and to more than 75.5% in 2013. According to long-term energy forecasts, the share of coal in heat production is expected to decrease [21].

As reported in [22], many of DH system around the world, particularly supplied with coal, require small modifications of modernization (i.e., retrofitting) to bring them to a reliable standard.

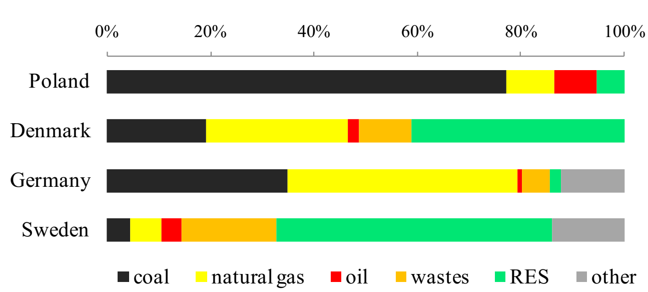

Fig. 1. The structure of the DH fuels consumption in chosen European countries.

The majority of the communal heating systems in Poland produce network hot water in solid fuel boilers (i.e. ones fired by pulverized coal or hard coal). A large number of such facilities are considerably worn out; therefore, a need to undertake a complete overhaul in a matter of several years will follow. Due to the considerable restrictions in the dust and SO_2 emissions, the heating industry faces the necessity of spending vast sums associated with the construction of costly new dedusting and desulfurization installations, while the emission standards for the case of newly built installations will be the strictest. Beside the technical wear of the existing boilers, in some district heating systems there is an additional problem associated with high-efficiency production of heat for network hot water during the off-peak period. The repowered hot water heaters are oversized in relation to the small requirements needed to cater for heat demand in the off-peak season; hence, the necessity to provide network hot water in the summer season brings the necessity to operate them under reduced load, which also means low efficiency of the process.

The major technological problems which are encountered in the communal heating sources operating for district heating systems can be summarized as follows:

- operation of boilers under considerably smaller load in the summer season,
- technical wear of the boilers burning solid fuel,
- necessity of adapting the emissions to the stricter norms.

The small degree in which the capacity of the sources clearly indicates that there is a need to optimize their capacity (adaptation to the demand for hot water in the off-peak season) while the technical condition of the installation reassures one in the claim about the urgent need to modernize the worn out boilers while concurrently reducing dust and sulfur emissions. An alternative to the high investment for these needs is offered by the repowering (retrofitting) of the existing sources with combined heat and power (CHP) gas-fired systems, often installed in the place of the old boilers for solid fuel.

Cogeneration of heat and power technology, compared to separate technologies, always offers the possibility of increasing the efficiency of the energy production and results in a decrease of primary energy use [23]. Fuel savings, in turn, lead to smaller emission of air pollutants from the combustion processes and decrease of the quantity of solid waste from burning solid fuel.

The possible, systems which can be used to repower the municipal heat generating plants are offered by:

- CHP systems with a combustion engine and a system of heat exchangers,
- CHP systems with a gas turbine and waste heat recovery boiler.

Due to the considerable investment needed and high exploitation cost (relatively high price of natural gas) the repowering into CHP system only makes sense for the case when it can be exploited over the period of entire year with the only exception for necessary maintenance. The longer period in which the CHP system can operate is justified by the higher revenues from the production of electricity (production for the internal load of the plant or to be sold outside). Therefore, a repowered communal heat generating plant has to operate also in the off-peak season in order to provide network hot water or (less frequently) to provide heat needed in some technologies. The system operating in cogeneration can by applied for base load operation over the period of the entire year.

An optimally selected and configured CHP system is one which not only leads to the savings in the use of the chemical energy of the fuel but also has to offer economic benefit. However, applying of cogeneration does not make the offer an automatic improvement

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