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Equipment sizing in a coal-fired municipal heating plant modernisation project with support for renewable energy and cogeneration technologies

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ABSTRACT

The paper presents results of design parameters optimisation of a wood chips fired steam boiler based heat and power block in a sample project of coal fired municipal heating plant modernisation. The project assumes the conversion of the heating plant into a dual fuel heat and power plant. The problem that is presented is selection of cogeneration block structure and thermodynamic parameters taking into account financial support mechanisms for cogeneration and renewable energy technologies. There are examined energy conversion and financial performances of the project. The results show that without the financial support the project is not profitable although it generates savings of primary energy of fossil fuels. If an administrative incentives are applied the optimal technical solution is different than suggested by energy conversion efficiency or fossil fuel savings. Financial calculations were performed for Polish marked conditions in the years 2011 and 2014 showing the impact of relatively short term variations of prices and support intensity on optimal plant design parameters.

1. Introduction

A possible way for deployment of Renewable Energy Sources (RES) technologies into the energy market is modernisation and retrofitting of existing fossil fuel fired production facilities [1,2]. In many European locations municipal heating systems are potential candidates for application of biomass fired cogeneration plants. Such projects can lead to both fossil fuels savings and emission reduction. In each case however the effects will be different depending on selection of technology, structure, size, design and operating parameters of an energy conversion plant solution. The key problem is optimisation that takes into account proper objective function and constraints such as parameters of energy carriers, load profiles, energy and material balances, machinery characteristics, economic figures, availability of resources and fuel supply issues [3].

Usually in industrial practice optimisation is carried out using an economic objective function, expressed by the local financial effect [4,5]. Examples of such functions are: annual profit, total annual cost, Nett Present Value of a project (*NPV*), Internal Rate of Return (*IRR*) or payback period. Such approach is justified by the fact that investment decisions are made by individual investors expecting benefits from an invested capital. The problem and example of an optimisation study were presented by Raiko et al. [6]. The target function they used was the Return On Investment (ROI). Savola et al. [7] presented a mixed integer nonlinear programming model for small-scale combined heat and power plant synthesis and operation. The objective function suggested by the authors was maximising the profit from an increased power generation. They claim that a higher power-to-heat ratio would increase power production and could improve the economic feasibility of new small-scale combined heat and power (CHP) plant investments. Marbe et al. [8] presented a design study for a municipal cogeneration plant that supplies customers with hot water and process steam. The objective function selected for analysis was maximum profit for an investor. The authors showed that the cost-effectiveness of the proposed technologies is highly dependent on the financial value of the certificate of origin for electricity and very sensitive to the price of biomass.

Nowadays it appears that renewable energy projects are heavily dependent on financial support via policy and legal regulatory requirements. Pantaleo et al. presented that specific subsidies for heat and power generation from biomass are required for a profitability of the investments [3]. Moreover the reliability of subsidy mechanisms is crucial as the financial support is one of the most influencing factors for biomass CHP technology [9]. On the other hand the existing support systems for renewable energy

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Nomenclature

A	heat transfer area, m^2
a_i	empirical coefficients (in the calculations performed: $a_1 = 6$, $a_2 = 0.25$, $a_3 = 0.14$)
c	unitary cost, PLN/natural unit
CF	cash flow, PLN
C_P, C_T	pressure and temperature related boiler cost multipliers
E	energy, kJ
h	specific enthalpy, kJ/kg
i	specific investment cost, USD/specific natural unit
IT	income tax, PLN
k	heat transfer coefficient, W/m^2 K
K	total cost, PLN
LHV	lower heating value, MJ/kg
m	mass, kg
$\dot{m}$	mass flow, kg/s
p	pressure, kPa
P	power, kW
v_p	average specific volume of condensate in a pump, m^3/kg
Q	heat, kJ
$\dot{Q}$	heat exchanger heating duty, kW
r	discounted cash flow, PLN
t	temperature, °C
T	temperature, K
w	moisture content, %

Greek symbols

β	heat loss coefficient ($\beta = 0.98$)
δ	binary value 0 or 1
η_{eB}	boiler energy conversion efficiency
η_m	mechanical efficiency
η_g	electric generator efficiency
η_i	isentropic efficiency
σ	power to heat ratio of cogeneration plan

Subscripts

a	ambient conditions
b	beginning of a heat exchanger
bio	biomass
BT	back pressure turbine
BWH	boiler water heater
ch	cooling water
co	certificate of electricity origin
cogen	cogeneration
CO_2	carbon dioxide
D	deaerator
e	end of a heat exchanger
el	electric energy
ep	emission permit
exp	exploitation
EBT	extraction back pressure turbine
ECT	extraction condensing turbine
f	heating network feedwater
FB	fluidised boiler
gen	at generator output
GB	grate boiler
in	input conditions
min	minimum allowable value
MHN	municipal heating network
n	nominal value
NR	nonrenewable fuel
oc	own consumption
out	output conditions
p	steam
P	pump
r	heating network return water
s	isentropic conditions
system	national energy system
ref	reference value
TC	condensing turbine
TLP	low pressure (condensing) section of extraction condensing turbine
q	heat
w	heating network water
WB	coal fired water boilers

technologies generate relatively high political and market risk [10]. Experience shows that regulations in both the areas of support and the amount change in a relatively short time horizon (shorter than the lifetime of a project). Therefore despite a high potential for RES technologies the number of new investment projects, especially in the range of distributed plants, is not satisfactory. On 27 March 2013, the European Commission published its first Renewable Energy Progress Report under the framework of the 2009 Renewable Energy Directive [11]. A general conclusion from the report is that the market penetration by renewable energy technologies is lower than it was expected. The projections show that almost all EU member states will fail to meet their 2020 minimum trajectory targets if no further policies and measures are implemented.

In the light of the policy targets it was found to be interesting to study how the available financial support for new investments affects the optimum scheme and size of a planned energy conversion plant. In this paper the issue of objective function selection, and in particular its impact on the choice of the optimal solution in the situation of supporting renewable energy technologies and cogeneration is discussed. A sample project of coal fired municipal heating plant modernisation is taken into account. The existing coal fired heating facility is considered to be converted into a duel fuel heat and power plant. The project leads to on-site reduction of coal consumption and diversification of fuel mix, global reduction of fossil fuels consumption and CO_2 emission within the national energy system.

2. Support mechanism

The project comprises two technologies important for the energy policy, that are cogeneration and renewable energy conversion. Therefore under current legal regulations in most of the EU member states it is eligible for financial support. In order to achieve the policy targets different countries use various support mechanisms for promoting new investments. The existing support schemes are mostly the administrative ones. Current support measures are either direct (investment grants, price subsidies, tendering schemes, tax exemptions, etc.) or indirect (research funding, below-cost provision of infrastructure, positive discriminatory rules) [11,13]. The most important for promotion of new investment projects are the direct economic incentives [2,6,8,11].

The biggest attention is paid to the electricity generation sector. Present regulations make the total value of financial support dependent on the amount of generated electricity. The dominating