Performance Improvement of a Romanian Cogeneration Plant Through Optimal Coverage of Heat Load

Diana Tuţică, Ştefan-Dominic Voronca, Eduard Minciuc, Roxana Pătraşcu, George Darie
Department of Energy Production and Use, Faculty of Power Engineering
University Politehnica of Bucharest
Bucharest, Romania
dianatutica@gmail.com; sdvoronca@gmail.com; eduard_minciuc@yahoo.com; op3003@yahoo.com; george.darie@energy.pub.ro

***Abstract*— The energy supplier analyzed in this paper has 2 Rolls-Royce engines (M1&M2), running on natural gas, and producing 6.8 MW_e of power and 5.6 MW_{th} of heat each. In order to cover the heat demand during winter, the plant functions with both M1&M2 and one of the two hot water boilers (HB), the new one 58MW_t or the old one 29MW_t. One major problem consists in large and often variations of the heat demand, which occur in the warm season and impose frequent modification of the operating loads. The aim of the paper is to optimize the operating regimes of the plant. The functioning characteristics at partial loads of the two engines were determined, based on the manufacturers' data, and the data measured at different partial loads.**

***Index Terms*-- CHP, energy efficiency, gas engines, heat recovery**

I. INTRODUCTION

In order to optimize the operating regimes, the paper aims to determine the optimal functioning mode of the plants' components, in order for the produced energy to satisfy with precision the heat demand. The approached field of this study is based on the concept of the combined power, heat and/or cold low and medium production [1]-[3].

In Romania, Combined Heat and Power Plants (CHPP) benefit of a support scheme stipulated by national low that foresees a Bonus (€/MWh) for each unit of produced and sold electricity. To receive the high efficiency cogeneration bonus, a plant must cumulatively meet several mandatory conditions [4]:

- power plant dimensioning in order to ensure an useful heat demand;
- total energy production with an overall efficiency of at least 75%;
- and a fuel saving of at least 10%, in comparison to the separate production of both heat and power [5].

The value of the Bonus is also stipulated by law, and is available from 2010 to 2021.

II. CASE STUDY

A. *Definition of the main scenario*

The development of the model is based on the cogeneration configurations made to meet the useful thermal and electric demand of urban consumers.

According to the legal provisions, the sizing of the cogeneration plant is made so that the heat recovered from the power generating equipment ensures the coverage of a useful heat load. In other words, the amount of global heat, recovered from the whole configuration, must satisfy the demand of the consumer / customers. It results that another constraint imposed on the studied devices is given by the following relation:

$$E_T(t) \leq E_{t,u}(t) \tag{1}$$

Where,

E_T (t)- represents total amount of heat that can be recovered during the plant functioning, expressed kWh_t;

$E_{t,u}$ (t)- is the total quantity of useful heat, required by the customer served by the cogeneration plant, also expressed in kWh_t;

(t)- represents the time, expressed in hours.

Very important to define are the minimum or maximum technical operating values, as well as restrictions on emissions of pollutants and environmental factors.

In this regard the referred scenario (S_0) is defined, in which the thermal engines function at the base of the demand curve, in order to ensure the necessary of thermal agent required for heating and hot water. The hot water boilers complete the necessary of heat in order to cover the heat demand curve during wintertime. In Fig. 1, the engine operating mode is illustrated in the referred scenario, during 10 months of 2016. Subsequently, the following scenarios were defined S_i, with i comprised from 1 to 4, representing operating mode alternatives of the engines running on partial loads and in

978-1-5386-3943-6/17/$31.00 ©2017 IEEE

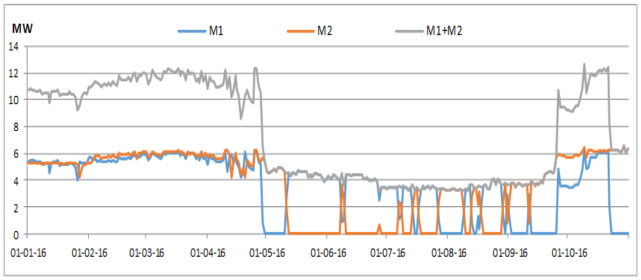

Figure 1: Heat generation from: M1-gas engine 1; M2- gas engine 2;

different configurations. Each S_i was correlated to both economic variables and technical variables, which must be met in conformity to the into force legislation. Scenarios' S_1 and S_2 hypothesis is to integrate into the main configuration some new aggregates, in order to produce cooling using the heat recovered from the engines, respectively to achieve thermal energy storage. While scenarios S_1 and S_2 are still in a testing phase, this paper presents a comparison between scenarios S_0 and S_4.

B. *Definition of the analized scenario*

In order to analyze the technical and economical parameters of the S_4 scenario, regarding the partial load operating mode, the functioning characteristics of the two engines were determined, based on the manufacturers' data [6], (at a 100%, 75% and 50% of the nominal load) and the data measured at different partial loads. For each engine we realized four tests: one at the nominal load, and four others at 98.1%, 88.8%, 76% and 50.6%. During testing one reciprocating engine, the second one was shut down. All measured data were computed and an energy balance has been done for each partial load.

Performances parameters of one of the two engines are shown in table 1.

TABLE I. ENGINE PERFORMANCES DURING EACH TEST

Parameter	**Symbol**	**Units**	**Test S1 98,1%**	**Test S2 88,8%**	**Test S3 76%**	**Test S4 50,6%**
Heat rate	q	kWh/ kWh	2.302	2.303	2.301	2.456
Electric efficiency	η_{el}	%	43,44	43,43	43,47	40,72
Thermal efficiency	η_{th}	%	38,37	41,97	48,59	48,95
Overall efficiency	η_{gl}	%	81,82	85,39	92,05	89,68

From Table I we can observe that heat rate, defined as ratio between heat consumption and generated power, has an insignificant variation between 76% and full load. For every partial load both electric and thermal efficiencies are satisfactory, if all the heat from exhaust gases is recovered. For tests 3 and 4, the entire quantity of heat from flue gases was recovered, leading to a stack temperature of 59 to 68 ºC. This was possible because of the decrease of the flow.

The problem is that, during summer, the heat demand is lower than 3.9 MW. In this case, only a part of the exhaust gases flow will pass through heat exchangers. Due to this fact, for tests 1 and 2, the temperatures at stack were around 167.6 ºC, respectively 131.6 ºC, while design temperatures were 100 ºC for 98,1% and 68 ºC for 88,8% of nominal power load. In the case of test 2, for a fuel consumption of 13901.419 kW and a power generation of 6037 kW (88.8%), thermal efficiency is decreasing to 27,91%, leading to an overall efficiency of 71% which is lower than the mandatory minimum efficiency of 75%.

For this reason, in this period of the year, in S_0, the CHPP is functioning with one engine at partial load, trying to satisfy the heat demand, corresponding to equation (1). The main consequence is that the amount of electricity is inferior to the nominal amount and is sold at a price almost three times lower than normal. The profile of the CHP plant is illustrated in Fig. 2.

III. ECONOMIC ANALYSIS OF THE PROPOSED SCENARIO

In the current situation, the CHPP is operating with one engine, at a high partial load of 88%, the purpose of the main activity being to sell a maximum amount of electricity. However, since the heat demand is much lower than the recoverable amount of heat corresponding to this partial load, there is a certain quantity of heat in the flue gases that is discharged into the atmosphere.

In order to reduce fuel consumption, one of the solutions would be to reduce the electrical load of the engine to a value that would cover the heat demand for the summer period (about 3900 kWh), but also to recover as much heat as possible from the quantity available in combustion gases. This would mean operating the engine, in summer mode, at a 50% electrical load (S_4). In this situation, both the amount of electricity sold and the fuel consumption are reduced. The technical comparison between the main functioning scenario and the half load scenario is illustrated in Fig. 3.

We took into consideration a period of 3600 hours for the operation of the CHPP during warm seasons, and the same amount of recovered heat for both scenarios.

In this model, the objective function is the profit obtained by optimizing the operation of the cogeneration configuration, which must be maximized. To that end, the components of the profit that depend on the operation of the plant are determined, and components that are not influenced by this type of optimization, such as maintenance costs and staff, are neglected.

In other words, fuel costs are taken into account, which for cogeneration plants represent almost all variable costs. Other variable costs, with different chemicals or additives required in operation, with technological water, etc., can be taken into account as a small percentage of the cost of fuel.

The before mentioned cost could also include CO_2 costs. These may be associated with a fuel surplus if we take into account the fact that they are calculated on the basis of emission factors that determine the tonnage of CO_2 emitted per unit of burned fuel.

Income is the result of selling the products of the CHPP: electricity and thermal energy in the form of hot water or steam.

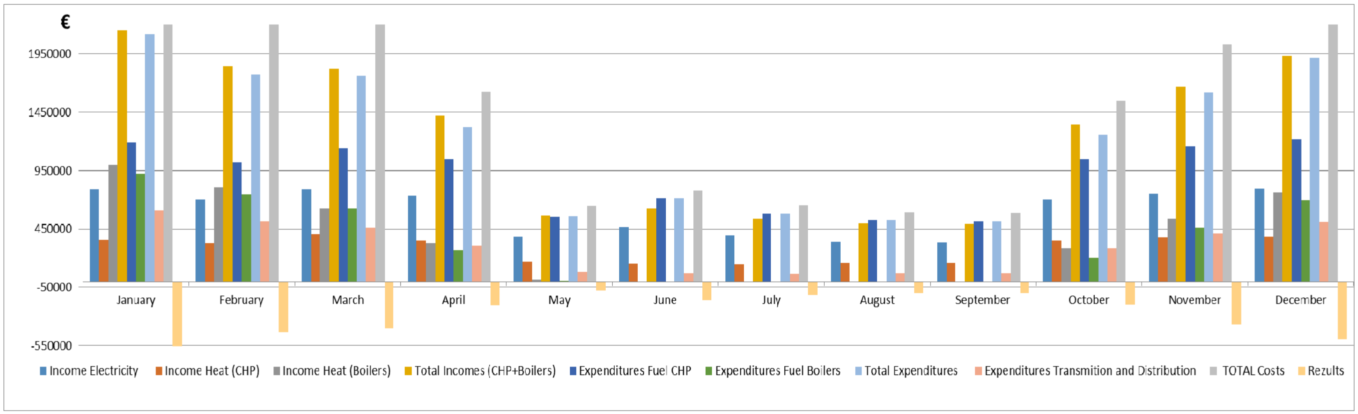

Figure 2:Economic profile of the CHP Plant in S_0

Taking into account the legal provisions in force, in order to meet the criteria for high efficiency cogeneration, the producer is obliged to sell all the electricity produced in cogeneration on the competitive energy market. Economic results are illustrated in Fig. 4.

In other words, electricity can be sold on the market for the following day at the closing price of the market and / or on the regulated market, at a minimum reference price of at least 90% of the average market price for the next day, from the previous year [7].

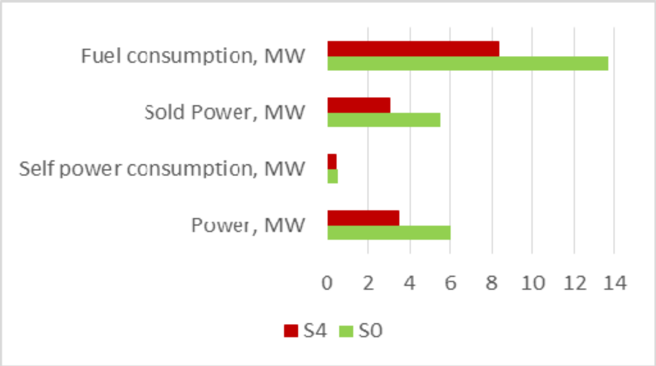

Figure 3. Comparison between Power productions in S_0 vs S_4

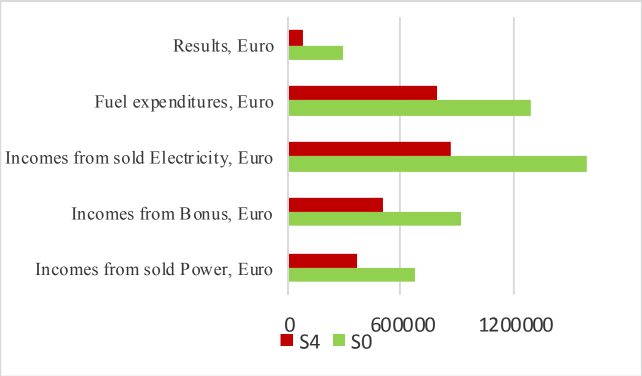

Figure 4. Comparison between economic results in S_0 vs S_4

In some cases it may happen that the electricity production does not fully cover demand, in this case it is used to purchase the amount of electricity on the next day market. Buying energy at the same price of the market as the energy sales' price, we can also consider purchasing energy as an income, but with a changed (negative) sign, in order to simplify the calculation model.

Thermal energy is supposed to be capitalized through long-term contracts, at statutory reference prices, by selling it to the consumer / customers of the studied cogeneration plant [8].

The input data for the studied application are: a). Thermal and electrical energy applications; and b). Predicting the price of electricity on the competitive market.

Entry data is a function of the optimization period and has an hourly character. The distribution of heat and electricity production between the various sections constituting the configuration must meet both the limitations imposed by the technical restrictions on the equipment and the legislative requirements for the qualification as high efficiency cogeneration.

In the paper the results of the economic calculations are presented briefly, in a simplified manner. In this respect, the model was based on an average electricity price of 34 € / MWh, an average value of the high efficiency cogeneration bonus of 46 € / MWh and an average fuel price (taking into account the above mentioned previously) of 26.3 € / MWh.

Considering that in both situations, the engine delivers the same amount of heat for district heating, the analysis did not take into account the revenues from its sale. As we can see, in the case of accessing the support scheme, the reduction of the revenues exceeds the savings achieved by reducing the fuel consumption in case of operation at a 50% electric load, compared to the 88% load operation. In percentages applying scenario 4 will lead to a decrease of 61% of the energy consumption compared with the main scenario, however it will lead also to a decrease of the incomes, with 55% from the revenues generated when operating at 88% partial load.

Therefore, this situation is not profitable for the case of operating modern and efficient equipment. In such situations, where a significant part of the heat consumers have disappeared, as is the case of Romania, it is not worth a big deviation from the nominal operating mode, but rather a search for polygeneration solutions (e.g. cooling production based on heat recovered from engines) or thermal energy storage.

IV. CONCLUSIONS

After analyzing different operating regimes, the following aspects were identified: the overall efficiency and the fuel savings, when reducing the engine load, easily remain within the demanded values of high efficiency cogeneration (overall efficiency > 75% and fuel savings > 10%); in the case of the partial load functioning of hot water boilers, a considerable degrading of the efficiency and a rise in fuel consumption was observed; also, due to the high engine flexibility, it is more efficient (considering the current produced power and primary energy prices) for the plant to function on a partial load, in comparison to an on-off case of scenario.

The paper contributes to indentifying the best practices of covering the heat demand curve for internal combustion engines combined heat and power plants, the methodology being applicable at a large scale and will be improved by taking into account modern plant retrofitting. By obtaining a better heat demand coverage, the economic agent will be able to manage the primary energy consumption more efficiently, to obtain the high efficiency cogeneration bonus and hence, the stabilization and even improvement of income.

ACKNOWLEDGMENT

This paper work has been funded by University “Politehnica” of Bucharest, through the Transfer of knowledge to the economic agent “UPB – Bridge Grants” Program, Identifier: UPB – PN-III-P2-2.1-BG-2016-0154. Research project title: “Increasing the competitiveness of ENET SA Focsani through the development and diversification of the offered services and optimization of the modern technologies of combined production of electric and thermal energy”

REFERENCES

[1] A. S. Siddiqui, C. Marnay, O. Bailey, and K. H. LaCommare, “Optimal selection of on-site power generation with combined heat and power applications,” Int. J. Distrib. Energy Res., vol. 1, no. 1, pp. 33–62, Jan.–Mar. 2005.

[2] W. El-Khattam, K. Bhattacharya, Y. Hegazy, and M. M. A. Salama, “Optimal investment planning for distributed generation in a competitive electricity market,” *IEEE Trans. Power Syst.*, vol. 19, no. 3, pp. 1674–1684, Aug. 2004.

[3] Sanaye S, Shokrollahi S. Selection and sizing of prime movers in combined heat and power systems. ASME; 2004. p. 613-21.

[4] D. Tuțică, P. Voicu, M. Norişor, G. Darie, A. Badea, Analyse de l’impact des règlementations européennes sur les producteurs d'énergie en cogénération, en Roumanie, Proceedings of the Conference COFRET 2012, “Efficacité énergétique – Sources d’énergies renouvelables – Protection de l’environnement”, 11-13 Juin 2012, Sozopol, Bulgarie, pp 497 – 502;

[5] CE Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU Strategy for Heating and Cooling, part 1 and 2, Brussels, 16.2.2016 SWD(2016) 24 final

[6] Brochure RR Medium Speed Products, Bergen Engines, https://bergen.rolls-royce.com/Portals, © 2017 BERGEN ENGINES AS

[7] A. Adam, I. Barbieru, M. Gavrila, Thermal audit of a CHP Plant : mesurements of operating parameters of 2x 6,8 MW reciprocating engines, ICEMENERG Bucuresti 2016

[8] *** „Methodology for setting prices and quantities of electricity sold by producers on the basis of regulated contracts and prices for thermal energy delivered from plants with cogeneration groups”, Approved by the Notice no. 4 of 17 January 2012, OPCOM