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A REVIEW OF OPTIMAL TECHNOLOGY SELECTION AND OPERATION OF A RESIDENTIAL CHP

Tutica Diana, Minciuc Eduard, Patrascu Roxana, George Darie
Power Engineering Faculty - University Politehnica of Bucharest, Romania

In order to optimize the performances of a residential Combined Heat and Power Plant (CHP), the authors aims to determine some of the optimal technological solutions that can be applied to the analyzed plant.

The energy supplier analyzed in this paper has 2 internal combustion engines (ICE1&ICE2), running on natural gas, and producing each almost 7 MW of power and 6 MW of heat. In winter, in order to cover the heat demand, the plant functions with both ICE1&ICE2 and one of the two hot water boilers (HB). One major problem, which occur in the warm season, consists in large and often variations of the heat demand, and imposes frequent modification of the operating loads. To better understand the behavior of the engines, were determined the functioning characteristics at partial loads of the two engines, based on the manufacturers' data, and the data measured at different partial loads.

One of it is to find the functioning mode of the plants' components that will lead the produced thermal 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, in which case, the receiving of the high efficiency cogeneration Bonus is a mandatory condition.

Sometimes, optimizing only the operating regimes is not profitable for the case of modern and efficient equipment, such as the analyzed CHP, and especially where a significant part of the heat consumers have disappeared, as is the case of Romania. In this cases it is not worth a big deviation from the nominal operating mode, because this will lead to poor performances results, but rather a search for polygeneration solutions (e.g. cooling production based on heat recovered from engines, use of the captured CO2 into chemical processes, use of part of the mechanical work or of the resulted wastes etc.) or thermal energy storage.

Keywords (3-5 keywords) CHP, energy efficiency, gas engines, polygeneration, heat storage.

INTRODUCTION

In Romania, CHP benefits of a support scheme that foresees an amount of money (Bonus in €/MWh) for each unit of produced and sold electricity. To receive this subsidy, a producer must cumulatively meet several mandatory conditions:

a) The CHP has to be designed so that the heat recovered from the power generating equipment ensures the coverage of a useful heat load [1];

b) The plant has to realize, compering to the separate production of the same amount of useful energies, a fuel saving of at least 10%, [2] and

c) The overall efficiency of all produced energies divided by the energy consumption, must overpass 75% [1], [2].

If the three conditions are not met, there will be no bonus and therefore economic operation of the plant will be seriously affected. The value of the Bonus is also stipulated by law, and is available from 2010 to 2021 [3].

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 an existing useful heat load. In other words, the amount of global heat recovered from the CHP configuration, must satisfy the demand of the real consumer / customers. It results that another constraint imposed on the studied devices is given by the following relation:

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

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.

Depending on the number of cogeneration equipment that make up the configuration, the total amount of heat in the form "j" can be written as the sum of the thermal powers given by each section k, of the whole cogeneration unit K:

$$E_T(t) = \sum_{k \in K} E_{t,k,j}(t) \qquad (1.2)$$

In this model, the objective function is the profit obtained by optimizing the operation of the cogeneration configuration, which must be maximized. For this purpose, 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 personnel, are neglected (figure 1).

Starting from the ANRE formula for fuel economy and the definition of electric (1.3) and thermal (1.4) efficiencies for useful cogeneration energies in each section k and using each fuel type j over the analyzed time interval t, can be written as equation (1.5).

$$\eta_{el,cg,k} = \frac{E_{el,cg,k}}{E_{c,k}} \quad (1.3)$$

$$\eta_{t,cg,k} = \frac{E_{t,cg,k}}{E_{c,k}} \quad (1.4)$$

$$EEP_k = \left[1 - \frac{\sum_{t\in T} E_{c,k}(t)}{\frac{\sum_{t\in T} E_{t,cg,k}(t)}{\eta_{t,Ref,k}} + \frac{\sum_{t\in T} E_{el,cg,k}(t)}{(\eta_{el,Ref,k}+0{,}005)\cdot p_{pierderi\ evitate}}}\right] \cdot 100 \quad (1.5)$$

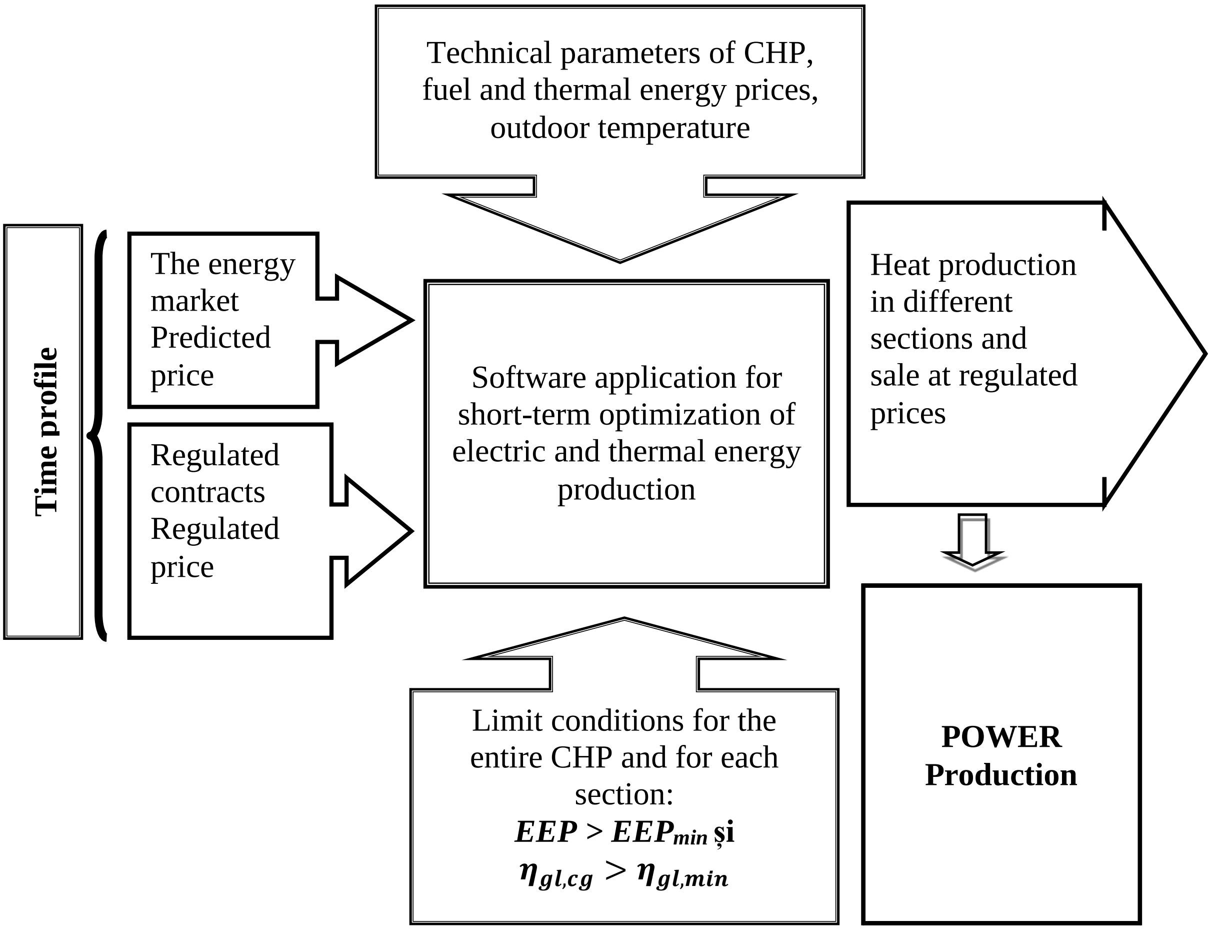

Fig 1. The block diagram of the energy and financial flows of the cogeneration plant

CASE STUDY

The energy supplier analyzed in this paper has 2 Rolls-Royce engines (M1&M2), running on natural gas, and producing 6.8 MWe of power and 5.6 MWth 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 58MWt or the old one 29MWt. 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 functioning characteristics at partial loads of the two engines were determined, based on the manufacturers' data, and the data measured at different partial loads.

In the first scenario there have been proposed energy efficiency measures with no cost or with low cost that can lead to energy savings and thus to financial savings for the analyzed company. This measures regard the optimization of the present manner of functioning.

Starting from the functions that define the comparison of the performance indicators at partial loads and the economic optimization model presented above, various scenarios of the cogeneration configuration of the ENET- Focsani power plant were analyzed. The current situation was defined as the S0 reference scenario, in which the engines operate on the basis of the thermal load curve, providing the heat demand for heating and hot water to the city. As in S0, during the warm period, the motors work alternately and the heat recovery is partially accomplished, it was proposed to analyze the assumptions in which the motors would follow the thermal load curve, thus reducing the generated power. Below (figure 2) is the less favorable case in which the motors operate at 50% of the nominal load, S1.

From the ICEMENEG [4] tests on the engines, it was found that during winter, for a complete cooling of the flue gases up to the 59-68 ^{o}C temperature, global shifts were higher than the minimum required for high efficiency cogeneration.

In summer, however, when the demand for heat drops below 3.9 MW, and only a part of the flue gas flow is passed through the heat recovery, reaching the chimney with temperatures above 170 ^{o}C, the thermal yield drops below 27.91 %, resulting in a global yield below 70%.

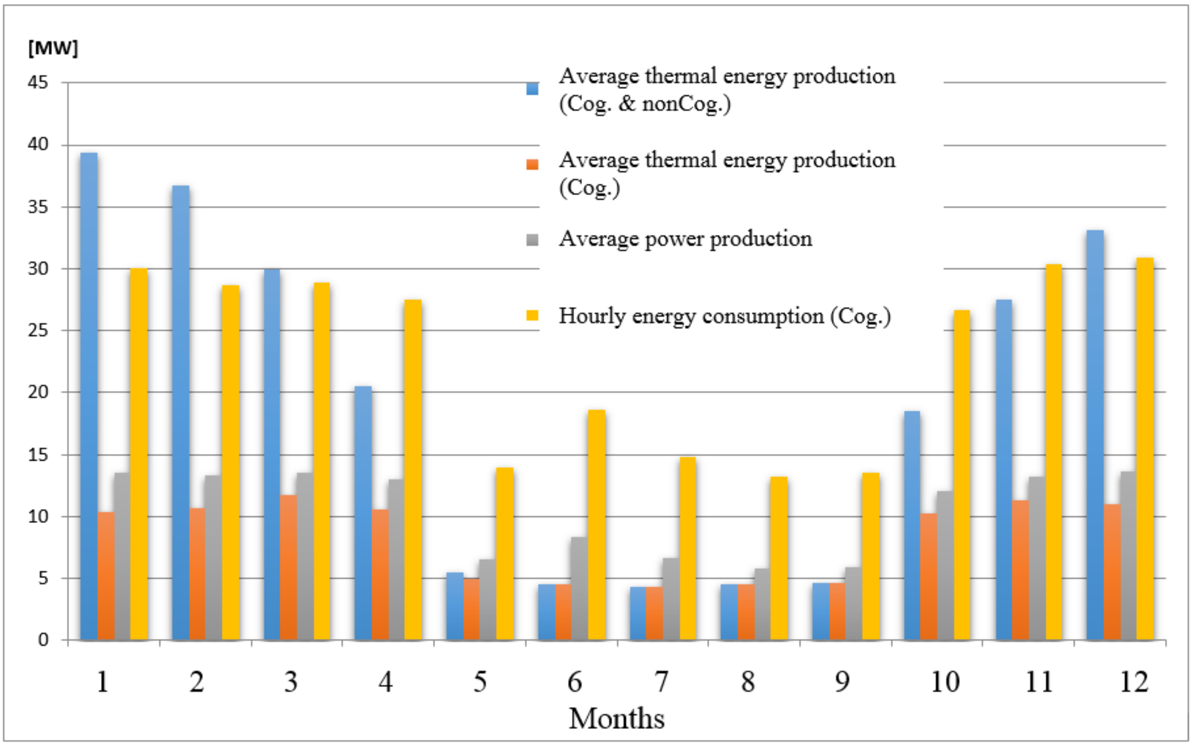

Fig 2. Energy profile of the CHP Plant in S_1

The period taken into account for the comparative analysis of the two scenarios is 3600 hours and the recovered heat is considered equal in both variants.

As can be seen from the results illustrated in Figure 3, the revenue reduction exceeds the value, the savings achieved by reducing consumption, when the motors operate at 50% of the nominal load and as long as there is a high efficiency cogeneration support scheme through the Bonus. In percent, even if a fuel economy is achieved by 61% higher in the S1 scenario, revenue is also reduced by 55% compared to the baseline scenario.

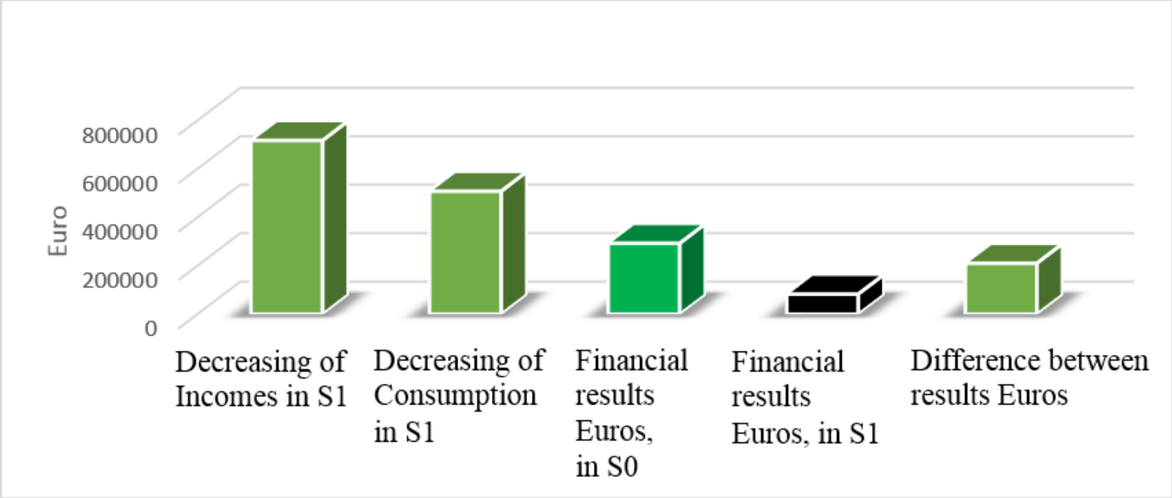

Fig 3. Economic profile of the CHP Plant in S_1 vs. S_0

In conclusion, as long as grants are awarded as bonus for high-efficiency cogeneration, the solution for reducing the electric load of the engines is not a profitable solution. This can become an interesting, in the conditions of rising natural gas prices and a drop in earnings due to the disappearance of the bonus. In the medium and short term, other scenarios, such as storing heat or using it to produce cold in the summer, should be considered.

To apply the heat storage solution as hot water, for the time there is no heat demand, we have the advantage of already having three tanks that were initially built to store the fuel oil which is no longer in use.

From this point of view, this measure could be the second low cost solution after the operating mode optimization. The most important investments will be to insulate the tanks and the network pipes between the plant and the storage places (figure 4 a).

Fig 4.a. Thermal storage in existing tanks

Fig 4.b. Emplacement of the future vegetables store (close to the CHP plant)

The third analyzed solution, is based on the CHP energy profile, showing an important potential for thermal energy to be used in a trigeneration system during the summer [5], [6]. Because optimizing only the operating regimes of a cogeneration plant can be often non-profitable, is worth rather to look for trigenartion solutions. Trigeneration, the combine generation of power, heat and cooling, can lead to greater fuel savings and automatically to a lower negative impact on the environment [7]. Of course, if there is demand for more than three types of useful energies, the best solution leading to the highest performance results will be the polygeneration (combined production of electricity, heating, cooling, mechanical work, capture and utilization of CO_2 from exhaust gases etc.) [8].

Taking into account that the coefficient of performance (COP) of absorption chillers using warm water with low temperature is about 0.6, there will be a production of approximately 1.7 MW of cold water, using the 3 availed MW of heat from engines. The 2 absorption chillers, having one absorption stage, are specially designed for cold water production with temperatures 7/12 °C and 5/9 °C using available heat from industrial processes or cogeneration units [9].

CONCLUSIONS

After analyzing the present situation of the cogeneration plant, it can be said that during the summer period when the district heating demand tends to zero the operation of cogeneration units can only be done with evacuating the total amount of available heat into atmosphere, thus not getting at all the advantages of cogeneration concept.

By 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 two others analyzed solutions for increasing the efficiency of the cogeneration plant during the summer period are to use the available heat during the summer time for thermal storage and use of the hot water when needed without starting the engines, or/ and to produce cold in an absorption chilling machine, through a trigeneration concept.

The trigeneration solution allows the plant to operate both engines during summer, by maintaining the production of electricity at an acceptable level. By making use of the heat potential through an absorption chiller to produce a significant amount of cold destined to a real consumer, the plant can work with a good overall efficiency and benefits from the aids schema.

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.

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