CASE STUDY CONCERNING THE OPPORTUNITY OF INSTALLING COGENERATION SYSTEM IN AN EXISTING INDUSTRIAL SITE

MN. Dumont, F. Maréchal, B. Kalitventzeff

Laboratoire d'Analyse et de Synthèse des Systèmes Chimiques
University of Liège
Sart Tilman Bât B6a
B-4000 Liège (Belgium)

ABSTRACT

The combined production of heat and power using cogeneration systems is one of the investigated area to reduce the global CO_2 production of the industrial activities in Europe. Due to the time scale of the investment, the appropriate sizing of a cogeneration unit is critical for defining the financial feasibility of the project. The possible efforts that could be made during this time scale for improving the energy efficiency of the process can make the cogeneration system oversized or even useless. In this paper, we present two methods that we applied to compute the appropriate size of a cogeneration system to be integrated to an industrial site. The first is directly based on the present steam consumption figures. This approach is easier and simpler but the solution is not sure for the future, it leads to a 5.6 MW gas turbine but without reducing the overall energy requirements of the plant. The second is based on energy integration including the optimal use of the steam network for CHP. This approach has the advantage to provide a reliable solution for the future. Using this approach, we have computed an energy savings potential of 60%, the energy requirements being satisfied by a 4.6 MW gas turbine, and the possibility of producing a complementary 3 MW with steam turbines.

INTRODUCTION

After the international agreement on the reduction of the CO2 emissions, the stress has been put on the efficient use of energy for producing electricity. In Belgium as well as in some other European countries, the electricity demand increases continually and the erection of new nuclear power plants is problematic. The 'rational use of energy' policy contributes to the promotion of high efficiency power plants using combined cycles but even with an efficiency around 50%, there is still 50% losses in air (at the stack) and in condenser (usually the river). Cogeneration systems offer a better solution that is to use an industrial process as a 'cold source' for the electricity production. This is called CHP (combined heat and power production).

As the investments are considerable, the economical viability of any cogeneration project has to be secured for the long term and the effort that could be made to improve the energy efficiency of the plant or to change the processes has thus to be considered in the evaluation, as well as the possibility of improving the scheduling of the plant operation to stabilise the energy demand.

In this context, we have been asked by an industrial operator to answer the question : "What is the steam requirements to be considered as a base load of the industrial site?". To answer this question, two methods have been applied:

- past and present steam consumption analysis to identify the present base load of the steam requirements to be satisfied by the cogeneration system and the potential for redistributing the steam consumption to increase the base load and reduce the peak demands;
- future steam consumption using energy integration techniques to quantify the potential for energy savings and therefore the possible reduction of the base load requirements in the future.

DATA GATHERING

The first step of the study was the data gathering. For past and present steam consumption, only data on steam production over a period as large as possible (at least one year) were needed. The production of waste heat boiler steam by an exothermic process was to be accounted for, the net steam production (or requirements) is obtained by balancing the process steam consumption and the waste heat boiler steam production. The steam production has been also confirmed from the fuel consumption records. The size of the gas turbine has to be estimated only from the net steam production.

For defining the future steam requirements, data of the different streams of the processes are needed. Hot and cold streams have to be identified to realise the energy integration of the site. Those data could be controlled data, design data or occasionally measured data. The different processes have been analysed in detail to compute the best possible energy integration of the site. When needed data were missing, the behaviour of the process has been deducted from the utilities study. Usually, different persons hold a part of the information needed, the data collection is therefore a task that consumes more than half of the time required to realise this type of study.

ANALYSIS OF THE PRESENT STEAM CONSUMPTION

The computation of the present base load for the steam requirements has been performed by analysing the records of one year. Deducting the waste heat boiler steam production, we defined the base load as being the steam production required over 95 % of the year 1995. This corresponds at least to about 13.75 t/h. Considering that 680 kW are necessary to produce 1 t/h steam, we obtain a heat load of 9350 kW to be produced in the recovery boiler of a gas turbine. It is good practice to consider that in combined heat and power production the ratio between electricity and heat is equal to 3/5. The size of the corresponding gas turbine is thus equal to 5.6 MW. It is be also possible to install a 1.3 MW steam turbine on the actual steam network. Those results are obtained without considering any change in the steam consumption for the future neglecting the effort made for rational use of energy in the processes. We would also highlight the fact that the maximum steam production corresponding to 23.75 t/h is achieved using a 9.7 MW gas turbine but only for 88% of the time.

DATA RECONCILIATION

For the precise study the quality of the results that will be obtained are strongly related to the reliability of the collected data. When redundancies were available, data reconciliation has been applied. The goal was to obtain a photography of the energy requirements that at least satisfy the mass and energy balances. In this study, the data reconciliation does not only serves to correct the measurements but mainly to build, from the data available, a coherent picture of the energy requirements of the total site plant. A complete model of the industrial site has been built. The measurements used are values from sensors, efficiencies assumptions, design data, etc.... The model has the following characteristics:

number of equations :	*1500*
number of variables :	*2320*
minimum number of measurements :	*820*
optimal number of measurements :	*>1000*
real number of measurements :	*1071*

We have modelled six of the eight process plants of the industrial site, some with more details than others according to the complexity of their steam demands and productions. The steam network was also modelled. From these calculations, we have identified different sources of inefficiencies in the process operation:

- the 6 boilers efficiencies (from 77% to 91.6%);
- the water and steam losses in the network (0.21 t/h for 40 t/h).

This procedure allows to characterise the temperature, pressure and flow rates of the different hot and cold streams of the processes to be considered in the energy integration study.

ENERGY INTEGRATION

The energy integration assumes that it is possible to synchronise hot and cold stream requirements. The computations have been done with mean values neglecting some highly discontinuous operations. For some sections of the plant, the energy requirements have been represented only by their corresponding steam requirements because investments were not expected in these sections. All the processes of the total plant have been considered simultaneously to draw the composite curves of the industrial site and compute the MER (Minimum Energy Requirements) of the plant. The energy savings potential (21605 kW) that could be realised in the plant was obtained by comparing the target value to the actual situation:

energy actually supplied:	*26120kW*
target :	*4565kW*

As a second step, we did analyse the technological constraints that might penalise the MER by restricting heat exchanges, i.e.layout constraints. The use of the integrated composite curves (Maréchal et al., 1996) allows to characterise the exchanges to be performed between the different sub-systems.

As a third step, we computed the MCER (Minimum Cost of the Energy Requirements). That gives us the optimal set of utilities to be used to satisfy the MER (4565 kW) at a minimum cost. Assuming the energy requirements as constant, we computed an electricity production target of 7.6 MW produced by a gas turbine (60%) and by two steam turbines (40%) to satisfy the energy requirements of 4.6 MW. The energy consumed for this combined production is of 15.2 MW. The efficiency of the electricity production is 50%.

A complementary study has been asked to compute the MCER considering the technological constraints. Four most promising alternatives corresponding to an energy savings potential of 10900 kW would be tested. In this case, new MER would become 15220 kW.

BENEFITS

The industrial process energy requirements are 26120 kW in the present case and 4565 kW in the optimal feasible energy integrated case (MER). Those requirements could be satisfied with boilers or/and with gas turbines (GT). The steam produced can be used directly on the industrial site or expanded first in a steam turbine (ST). We did analyse the costs using different process configurations for the two given energy requirements, the turbines and boilers efficiencies are detailed in figure 1.

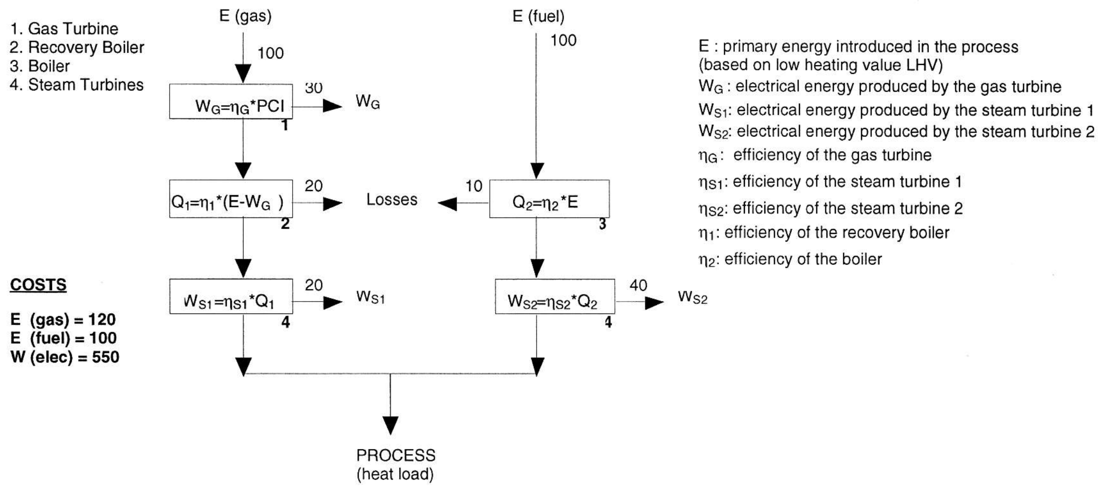

Figure 1 : different process configurations, turbines and boilers efficiencies

The comparison of different alternatives are given in table1. The reference case 1 is computed for an energy requirement of 26210 kW satisfied only with boilers. Cases 2 to 4 are computed for the same energy requirement but with different configurations, respectively with boiler and steam turbine (case 2); boiler and gas turbine (case 3); boiler, gas turbine and steam turbine (case 4). The size of the gas turbine is computed to satisfy the base load requirement. Case 5 is computed for an energy requirement of 4565 kW satisfied only with boiler. Case 6 is computed with a GT and a ST and the same energy requirement. The electricity efficiency refers to the energy consumed expressed in lower heating value (E). Cost in Monetary Units does not include investments.

CASE	**1**	**2**	**3**	**4**	**5**	**6**
Energy requirements of the plant (kW)	26120	26120	26120	26120	4565	4565
E (kW) (% of fuel)	29022 (100)	30483 (100)	37333 (49.9)	38794 (51.8)	5072 (100)	15217 (0)
W_G (kW)	0	0	5610	5610	0	4565
W_S (kW)	0	1315	0	1315	0	3043
Total electricity (kW)	0	1315	5610	6925	0	7608
Electricity efficiency	-	4.3 %	15 %	17.85 %	-	50%
Cost (M.U.)	2.9	2.3	1.0	0.4	0.5	-2.3
Investments	-	ST	GT	ST,GT	MER	MER,ST,GT

Table 1: Summary of the process alternatives

CONCLUSIONS

In this paper, we discuss two methods applied to evaluate the appropriate sizing of a cogeneration system to be integrated to an existing industrial site. The first method is based on the analysis of the present steam consumption. The base load of the steam requirements is used to define the size of the gas turbine. When the steam consumption is recorded over one year, this method is simple and rapid but ensures a valid solution only for the present situation. It does not take into account possible process improvements in the future, for instance a better synchronising of the steam requirements for peak shaving (increase of the base load) or the rational use of energy in the process plant (decrease of the base load).The second method aims at identifying the potential energy savings using energy integration. Even if data collection and reconciliation is a hard and time consuming task, it allows to obtain a good representation of the energy usage in the plant, to identify inefficiencies and to identify ways to improve the rational use of energy in this total site plant. Using graphical representations we have been able to quantify the MER target and the energy transfer required to integrate the processes of the total site in an optimal way. Energy integration evaluates the present energy efficiency of the plant and identifies the possible area for energy savings to be done in the future. The MCER of the site allows to determine the appropriate configuration of the steam network that will be used to exchange heat between the processes and that will maximise the combined heat and power production. The solution found with this approach could be considered as a minimum bound on the future energy requirements. The optimal size of the gas turbine corresponding to this situation is computed simultaneously.

The size of the gas turbine found with the second method is 4.5 kW to be compared with the size found with the first method which is 5.6 kW. The two solutions define the most appropriate minimum size for the gas turbine. Considering the overall energy efficiency of the combined electricity production, the two solutions differ from 18 % to 50 %. As the MER will probably not be reached during the investment period, another study would be necessary to analyse the possible benefits of using a bigger gas turbine to be switched off during minimum steam consumption periods.

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