Small and Medium Sized Gas Turbines for CHP: An Option to Improve Energy Efficiency of the Industrial Sector

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Synopsis

Results of a survey focussed on more important operational parameters of gas-turbine CHP plants working in the Italian industrial sector are presented.

Abstract

Industry energy consumption in Italy, as in the most of other developed countries, is about one third of the total consumption. Several different energy options are available to improve the efficiency with which energy is used in the industry sector. Nevertheless, the actual market penetration of those technologies has been hindered by legal, institutional, financial and technical barriers.

Laws n.9/91 and 10/91 and following Decree CIP 6/92 have promoted the utilisation of cogeneration technologies by independent producers. From 1991 to 1995, in Italy, the independent production has increased about 50%.
In the above mentioned increase, gas turbines have played a major role with respect steam turbines and Otto and Diesel cycle engines, as a consequence of their high electric efficiency, improved availability along with low production costs.

The paper describes the Italian situation in the sector, focusing on gas turbines plants with nominal power less than 30 MWe. After an overview of recent regulations affecting energy production, main findings of an energy audit campaign carried out in the industry sector are presented, with an indication of the potential market of cogeneration technology. Finally the results of a survey aimed to identify technical problems regarding the construction and operation phases of gas turbines in different industrial branches are discussed.

Introduction

Background

ENEA, the Italian National Agency for New Technology, Energy and the Environment, has carried out about 500 energy diagnosis and 60 feasibility studies in small and medium size enterprises (SMEs), over the last four years. Numerous energy saving measures have been identified and suggested for improving energy efficiency of several industrial branches. Results indicate an average pay-back time of 3 years and a potential energy saving worth 20 % of the total energy consumption.

The combined production of heat and power (CHP) was identified as the measure with the highest potential of implementation; in fact in more than 50% of the considered SMEs the installation of a CHP plant was identified as profitable energy efficiency investment.

Despite that, only two enterprises out of 500 planned and realised the plant. Several institutional and financial barriers are hindering the undertaking of measures for rational use of energy, in particular CHP plant. It is howev-

er difficult to understand why only a few of the projects have been accomplished despite the positive results of both the diagnosis campaign and the following feasibility studies, and the efforts made by enterprise's managers to overcome the above mentioned barriers.

Scope

With the aim of identifying the most relevant barriers for energy conservation measures, ENEA started with a set of actions among which was a survey concerning gas turbine CHP plants operating throughout Italy.
The survey concerned all CHP plants with a nominal power less than 30 MWe and regarded operational difficulties and availability of the main components. Analysis was performed on the main parameters such as energy efficiency, technical and managerial aspects, maintenance costs and procedures.

1. The Italian situation

The National Energy Plan (PEN) of 1988, singled out CHP as one of the most cost-effective options for the rational use of energy, particularly, in the industry sector. The following Laws n.9 and n.10 of 1991 modified the rules of electric energy generation by introducing incentives to independent producers. In particular, the Law n. 9 defines the situation whereby enterprises can be authorised for producing electric energy either by themselves or in the framework of a consortium, both for their own needs and for sale to the grid at fixed prices. Law n.10 provided financial support on a shared-cost basis for energy efficiency projects and assimilates the CHP as a renewable sources, considering its exploitation to be of public interest. Public support covers from 25% to 40% of the eligible investment costs.

The Decree n. 6/92 of the Inter-Ministry Committee on Prices (known as CIP 6) has been issued to increase the effectiveness of the above mentioned regulations, in particular simplifying the relationships between the National Board for Electric Power (ENEL) and the independent producers and setting an incentive based upon a credit for each kWh produced and sold to ENEL for the first 8 years of plant life. The type of plants allowed are: those utilising renewable sources; those of "assimilated" plants that is, those utilising cogeneration, waste heat, waste materials or fossil fuels from small fields; and plants utilising conventional energy sources but having an energy index (Ien) equal or higher than 0,51.

The sale price to the grid depends on the type of the plant, the condition of dedicating the full power or a share of fixed power, the fact of generating the electricity during peak or off-peak hours.
The sale prices of electric energy, referred to the year 1996, produced by plants utilising renewable sources or assimilated are indicated in the table 1.1.

To provide an exhaustive picture of the legal framework it is also necessary to make reference to the Decree 25/9/92 of Ministry of Industry that introduces four types of plants two of which are dealing with CHP.

The acceptance by ENEL depends on planned needs and according to the following priorities:

1) type of utilised source and expected value of the plant efficiency (Ien index);
2) plant site with reference to the local needs and the structure of existing electric grid.

The number of CHP plants with rated output higher than 10 MWe and dedicating the full power or a share of fixed power to ENEL and with date of completion by 1997 is 30 for a total power worth 3.132 MWe.

Table 1.1 SALE PRICES (L/kWh). Production from new plants utilising renewable and other authorised sources.

Plants	A) Plants dedicating the full power or a share of fixed power		B) Plants giving the surplus of production	
	peak hours	off peak hours	peak hours	off peak hrs
a) Hydroelectric:, basin, free stream (>3 MW)	274,3	47,9	basic price: 232,9 regularity: 41,4*R	
b) Hydroelectric: free stream (up to 3 MW)	144,1		basic price: 166,8 regularity: 41,4*R	
c) wind and geothermal	183,7		basic price: 232,9 regularity: 41,4*R	
d) Photovoltaic, urban solid waste and biomass	270,5		basic price: 377,4 regularity: 41,4*R	
e) Plants utilising fuel from processes or residual products	144,1		basic price: 166,8 regularity: 41,4*R	47,9
f) Plants utilising fossil fuel which are assimilated to renewable one on the basis of their energetic index (Ien)				
0.51<=Ien<0.6	150,3	47,9	basic price: 108,9 regularity: 41,4*R	
Ien>0.6	166,3	47,9	basic price: 124,6 regularity: 41,4*R	
g) Hydroelectric re-powering plants	196,1	47,9	basic price: 154,7 regularity: 41,4*R	

2. CHP in Italy

Referring to 1995, the total production of electric energy, without imports, in Italy was of 241.465 GWh, of which 40.172 GWh was by independent producers. The share of cogeneration has been of 27.923 GWh, with the following breakdown: 24% back-pressure steam turbine plants; 34% Rankine cycle; 1% Otto and Diesel cycles engines; 13% gas turbine; 28% combined cycle. Gas turbines, both simple and combined cycle, provided a share of 40% of the total production by CHP plants.

The amount of electric energy produced by cogeneration, in 1995, was 10% greater than the previous year. This development is related to only a negligible share of added production from new plants (the construction of most of them being currently in progress), instead it has to be referred to higher annual working hours of the plants, according to the cancellation of some incentives before existing on energy prices drawn from the grid.

3. Energy Audits - Synthesis of the Results

The energy audits campaign has been conducted, by ENEA, for 501 SMEs belonging to various branches of the economy, in the framework of the VALOREN Programme. For strategic reasons the audits have been implemented in SMEs, with a medium level of energy intensity usually constituting from 3 to 10% of the production costs. Large energy intensive sectors such petrochemicals, refining and continuous steel production presumably have the internal capacity and self-interest to perform such audits.

The average energy savings per enterprise was estimated to be 702 tons of oil equivalent (toe). The branches which have the largest absolute savings after the sugar and paper sectors are: ceramics, bricks, cement, chemicals and pharmaceuticals.

For the 501 firms audited in the last four years there was an annual energy consumption of 1,76 million tons of oil equivalent (table 3.1), about the 5% of the whole industry sector consumption. Approximately 1.500 possible energy saving opportunities have been identified, representing a potential savings worth 20% of total consumption. With an average pay-back time of 3 years, we can say that energy efficiency still has an important potential in the SMEs of Italy.

Table 3.1 General results

firms	energy consm.tion (tep/year)	measures n°	inv.mnt (ML)	savings (ML/year)	energy savings (tep/year)	saving/ consm.	invest./ saving (ML/tep)	pay-back (year)
501	1.762.517	1.513	587.568	195.238	351.806	0.20	1.67	3

Examining the audits by type of measures indicated, we see the outstanding role of cogeneration. It is in third place with respect to frequency, only the improvement in electrical contracts and plant modification proceeding it. Instead, in terms of potential energy saving, certainly a more important factor, it ranks first with more than two thirds of the total potential savings. The average pay-back time for cogeneration proposals was 3,2 years. On the other hand results from 25 feasibility studies, carried out by ENEA at the same period in several industrial branches, show an average value of the pay-back time of 4 years.

For Italy, an appraisal based upon the results of the diagnosis campaign gave a potential saving of 5 Mtoe achievable by implementation of cogeneration projects. As a consequence, we can confirm that cogeneration has a very important potential role to play for improving the energy efficiency of the industry sector.

4. Survey on operation of gas-turbine CHP plants

Due to difficulties to perform an in-depth research considering all gas turbine cogeneration plants existing in Italy at the date of 31/12/1994, it was decided to adopt an approach based upon a sample survey.
With the aim of selecting a suitable sample, all plants have been first divided in homogeneous groups with respect to their power, then the number of plants to be considered has been decided and finally the plants to be analysed have been chosen.

The gas turbines singled out, with power less than 30 MWe, have been a total of 112 units, installed in 88 enterprises with a total nominal power of 712 MWe. The plants have been subdivided in four groups: up to 1.500 kWe; from 1.501 to 5.000 kWe; from 5.001 to 15.000 kWe; from 15.001 to 30.000 kWe. A further subdivision has been made in each group with reference to the starting year of operation between plants with starting date before 1990 and after 1991. The choice of those dates comes from the fact that in 1991 a new generation of gas turbines has been introduced into the market, characterised by higher values of efficiency, reliability and lower specific

Table 4.1 Distribution of cogeneration plants with reference to the power value and first year of operation

kW	up to year 1990 number of plants	from year 1991 number of plants
up to 1.500	15	23
from 1.501 to 5.000	6	35
from 5.001 to 1.5000	11	8
from 15.001 to 30.000	8	6
Total	40	72

costs. Table 4.1 shows the distribution of cogeneration plants with reference to the power value and first year of operation.

A share of 63% of gas turbine were installed after 1991. Considering that the early group covers a period of about 30 years and the second group only four, we can see the confirmation of the positive trend in gas turbine plants due to tariff and regulatory changes as well as improved technology.

4.1 The sample

In order to guarantee the representativeness of the sample, it has been decided to include in each group, a number of plants ranging from 30 to 50% of the total. The number of plants for each group is shown in table 4.2. In total 43 gas turbine units were examined.

Table 4.2 The sample

kW	up to year 1990 number of plants	from year 1991 number of plants
up to 1.500	5	8
from 1.501 to 5000	3	11
from 5.001 to 1.5000	5	4
from 15.001 to 30.000	4	3
Total	17	26

Afterwards, through a random method, the plants to be considered in the survey have been selected. Those plants have been analysed through site-visits and the necessary data have been gathered by a questionnaire managed by the personnel of ENEA Consulting Centres in collaboration with the technical supervisors of the plants. Data collected have been verified only with reference to their general compatibility.
It has been possible to carry out 32 site-visits out of 35 plants for a total of 43 gas turbines out of 47 selected. Data collected have been elaborated through a data processing sheet.

4.2 Survey results

Before referring the most significant findings, it is interesting to outline that the distribution of the sample reflects very close the actual distribution of the plants in the different industrial branches, despite the approach adopted to built the sample.

Main results drawn from data processing are summarised below:
- *working state*: fourteen gas turbines out of forty-three have resulted out of service; six of them had been decom-

missioned due to the reaching of the end of their technological life, while eight of them have never started working. Reasons affecting the setting at work of the units deal with bad design (such lack of suitable foundations), lack of required authorisations, design shortages concerning the steam piping and set-up. These units have not been considered in the following analysis.

- *feasibility study*: it had been carried out for the most part of considered cases; that emphasises the importance of this tool in view of verifying the technical economical viability of the project. The feasibility study was implemented by the technology supplier of the plant in 11 out of 22 cases, 6 by energy managers of the firms, 1 was carried out by expert from consultant company, while for the remaining cases data were not available. As a consequence, it may be stated that the plant is sized, for the most cases, with reference to systems/components sold by supplier instead of the actual energy requirements of the firm. Only 3 projects have been sized according to energy (heat and electricity) needs of the process (for all these cases the feasibility study has been implemented by the technology supplier); for the remaining cases the plants resulted undersized with respect to the total energy requirements of the firm.
- *construction timing*: the average construction time required is about 1-1,5 years, with extreme values varying between 0,7 and 2,5 years.
- *maintenance and operating time*: maintenance costs and plant availability are two of the most important factors to improve plant profitability, thus the survey paid particular attention to those items. With reference to annual operating time, 85% of plants had worked more than 6.000 h/year and the same percentage for more than 20.000 lifetime hours. As expected to get a short pay-back time of the investment, the value of the annual working hours actually performed, was very high.

Before going ahead, it seems appropriate to briefly recall what “reliability” and “availability” in this context are.

Reliability: is the ratio between the difference of running hours and unscheduled maintenance hours for the last year and the running hours for the last year.

$$R = (he-hmc)/he$$

where:

he = running hours for last year

hmc = unscheduled maintenance hours for last year.

Availability: is the ratio between the difference of the running hours and the preventative and unscheduled maintenance hours and the running hours, for the last year.

$$A = [he-(hm+hmc)]/he$$

where:

hm = preventative maintenance hours for the last year.

Both preventative and unscheduled maintenance have been considered and it refers to the whole plant. Maintenance operations required less than 5% of the annual working time for 70% of the plants, while for the remaining plants the average value has been of about 15%. On the basis of these data, reliability resulted higher than 98% for 80% of gas turbines and availability higher than 97% for 42% of turbines. The value of reliability for gas turbines was a satisfactory result and in line with values of mature technologies; instead availability does not seem to be high enough. The values shown above (only 42% are over 97%) do not agree with the rates shown in literature.

This could be due to the fact that in that year general overhauling was performed, or the person interviewed assigned longer preventative maintenance times than the real ones or, finally, the variety of technology and the fact that it is new, with suppliers being unable to intervene in time which is technically acceptable and suited to a business operations.

Gas turbine packages suppliers provide the maintenance service for 70% of considered units, while in the remaining 30%, the service has been performed by the firm itself.

The average cost of the maintenance is inversely proportional to the size of machines; it ranges from 7 to 18

Lit./kWh, reaching the value of 20 Lit./kWh for the smallest machines (about from 9 to 25 % of generating costs). This cost includes that related to the complete overhauls.

The management of the plants have been performed by third parties only in 4% of the considered plants. This confirms the unwillingness of Italian SMEs to involve third parties in the various aspects of management of the firm.

Electric utilisation of the machines: this parameter has been calculated as the ratio between the average usable power and the nominal power of the turbines (ISO conditions) and the steam turbine, when applicable. The percentage of plant utilisation from the electric point of view was higher than 75% in more than 90 % of the plants. No corrections for temperature and altitude of the site have been included for the gas turbines.

Electric efficiency: processed data show, as expected, the lack of a correlation between electric efficiency and size of machines. Values are spread over a band going from 18 to 30%. The major part of the machines have got a value of efficiency in line with the medium value of the technology.

5. Conclusions

Improvements in competitivity and the reduction of polluting emissions to meet environmental targets require SMEs to adopt energy efficient technologies permitting to limit the share of energy cost in the production costs and to minimise the environmental impact linked to the use of fossil fuels. CHP technologies represent an interesting option to save energy or use it more efficiently in the case of several industrial branches. In particular the various configurations of the gas turbine cycle appear to be as one of most promising alternatives following the rapid development they have experienced with regard to efficiency and installation costs in recent years.

Main outlines from the analysis conducted are:

- There is a large potential for investment in energy efficiency projects in the Italian industry sector. In the majority of industrial branches, the cogeneration has turned out as one of the key technologies with the most high potential of energy saving and cost-effectiveness.
- Among available CHP technologies, the gas turbine was identified as the most promising option due to: the considerable improvements recently achieved in electric efficiency; the high value of availability and reliability index; the more simple concept of design entailing lower maintenance costs. Moreover, it has to be noticed that gas turbine generally gives better inter-connection with the process requirements.
- A considerable number of gas turbines have been found out of service as a consequence of bad design choices and lack of necessary authorisations. This could easily lead to lack of confidence by decision makers of industrial branches.
- Overcoming of problems highlighted in the previous item will require more industrial companies to use consultants to execute the feasibility study in order to define the optimal option with reference to characteristics of the process and help them comply with the increasingly stringent energy and environmental regulations.
- A maintenance programme is a critical factor to optimise running costs and maximise availability of gas turbines. This makes of high priority the establishment of contracts with specialised service companies, suppliers, etc., at agreed conditions and costs.
- Over the short to medium-term, it is initiatives such as simplifying the relationships between electric utilities and the independent producers and setting up of public support schemes, based for instance upon a credit for each kWh produced and sold to the grid, that are the most cost-effective to help increase market penetration of efficient energy technologies, among which small and medium sized gas turbines for CHP, into the industrial sector.

References

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