The paper deals with the economic assessment of the installation of gas microturbines by different types of MV customers and the main results of a test trial on a 45 kW microturbine. The recent technological developments in the field of gas turbines have permitted the realisation of small machines, with electric power in the range 25-100 kW (the so called microturbines) characterised by high specific power, limited specific cost and fairly good electrical efficiency. Moreover the manufacturers state that the machines have reduced acoustic noise and gas pollution as well as very limited maintenance needs. The microturbines could have a very large diffusion, not only for stand-by generation and automotive applications but also in the field of the distributed generation steadily connected to the electrical network. The microturbines can be connected directly to public network and used for combined heat and power production (co-generation), therefore they have a large potential range of applications that depend on the customer consumption profile (both electrical and thermal) and on the rate structure of natural gas and electric energy.

The aim of the activity described in the paper is to select situations of possible economical convenience for the installation by MV customers with reference to the Italian situation. The results of the analysis are the main economic figures calculated as a function of the operation hours, the quota of recuperated heat and the cost of natural gas.

The results show a potential area of convenience for the use of cogeneration microturbines that is particularly significant for application by “small” MV customers; these customers can maximise the utilisation of the microturbines and have a low sensitivity to potentially critical installation issues like noise and vibrations.

Finally the results of a trial on a 45 kW microturbine are summarised; the results show the potential pros and cons in the perspective of a wide diffusion of microturbines operating as embedded generators connected to the distribution networks. The test performed have shown that the reliability could be still improved and the noise emissions should be carefully considered in case of installation in residential areas.
ECONOMIC ASSESSMENT OF THE INSTALLATION OF NATURAL GAS-FUELED MICROTURBINES AND RESULTS OF PRELIMINARY TESTS

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INTRODUCTION

The recent major breakthrough in the gas turbine industry has allowed to construct small size machines that feature electric capacities ranging from 25 to 100 kW (the so called microturbines). A high specific capacity, a low cost and a somewhat significant power efficiency are all properties of these machines associated with low noise, low pollutant emissions and low maintenance requirements.

It is for all the above mentioned reasons that the microturbines are expected to have a significant market penetration in the niche of the stand-by (field generators), automotive and stationary power generation. Their design providing parallel, mains and co-gen power generation make them virtually fit the needs of a diversified range of users.

This paper is intended to provide a preliminary economic assessment of their application at MV users' (within the Italian power and gas tariffs relevant to non eligible customers) and to report the main results from the tests carried out on a 45 kW machine.

GENERAL ISSUES OF THE ECONOMIC ANALYSIS

The power capacity demand of a MV user is certainly such that in principle it requires the installation of many microturbines. According to the degree of detail used in this study, the decision of installing a k+1

nth machine is separate from that of installing the other k machines. Actually, there are no technical or economic constraints that prompt the installation of at least a given number of machines. The cost-benefit ratio of the k+1

nth machine is not influenced by that of the k-

nth (this kind of “modular” investment is one of the main properties of the distributed power generation).

An on-off full capacity operation of the machines being installed was assumed and the intervalation of the simple Pay Back Period of a machine investment with the operating hours and the natural gas supply cost was determined.

It is evident that any investment in the machines intended to meet the user’s peak loads (hence, a continuously decreasing operating time) rather than continuous duty requirements will be marked by a diminishing utility.

Installing a number of microturbines in order to put the user in the condition of disconnecting its plants from the public mains should generally be uneconomic, as the cost for the power supply in a power supply contract with a power distribution utility is generally lower than the yearly cost for the installation of the same capacity in microturbines. Therefore, it is profitable for a user to meet his peak load needs through the use of the power distribution mains (it should also be considered that waiving a power supply contract implies the installation of a higher microturbine number than strictly required in order to face any out-of-service condition).

CASE STUDY AND APPLICATION

The study covers a microturbine used to operate under full electric capacity over a given number of hours with recovery of a portion of the generated heat. This analysis applies to all machines a user assumes to install later, the operating time of which is expected to decrease progressively. It is fundamental that in the above case the user may supply back to the production process the co-generated heat in order to take advantage too of the lack of natural gas combustion in a conventional boiler.

The assumptions on which this study is based are as follows:
- Continuous operation of the machine under full capacity.
- No variation in the user’s power supply type because of the machine installation.
- Demand saving of a corresponding capacity from the power distributor.

This may reasonably be the case of a MV user with a capacity demand ranging from some hundreds kW to 1-2 MW. Beyond these values it would be more convenient to use co-generation units based on gas turbines currently available for such capacities with more economic installation costs and better efficiencies than those of the microturbines.

The parameters of the study include:
- Actual costs and efficiencies of the microturbine
- Operating time of the microturbine
-...
-Percent recovery of the heat generated by the microturbine
-Natural gas cost (tariff +taxes) in industrial and handicraft applications

Microturbines data

The microturbine data used in this study are shown in Table 1. The leading manufacturers state that an improvement in costs and performances could be attained in the short-average period.

**TABLE 1- Microturbine Data**

| Investment cost (power generation + heat recovery) | 1000 Euros/kW |
| Installation/investment cost | 10% |
| Yearly O & M cost/investment cost | 5% |
| Service life | 10 years |
| Electric efficiency under cogeneration (\(\eta_{el}\)) | 21% |
| Global efficiency under cogeneration (\(\eta_{tot}\)) | 85% |

Formulas

**Cost of the generated kWh.** The cost of the kWh generated by the machine and entirely consumed by a user may be assessed on the basis of the above assumptions as function of either the turbine operating time or the methane cost for power generation.

The formula for the calculation of the microturbine-generated electric kWh cost is as follows:

\[
\frac{C_{inv}}{a_{n,i}} + \alpha_{n,i} \cdot C_{inv} \cdot \frac{1}{h} + \frac{C_{gas - g}}{pci \cdot \eta_{el} \cdot k}
\]

where:
- \(C_{inv}\) investment cost in Euro/kW (including the installation expenditure)
- \(\alpha_{n,i}\) investment mortgage factor (annuities over \(n\) years at \(i\) rate)
- \(\alpha_{n,i}\) yearly cost for plant operation and maintenance expressed as percent value of the investment cost (Euro/kW/year)
- \(h\) turbine operating hours/year
- \(C_{gas - g}\) methane gas cost for power generation in Euro/m³
- \(pci\) methane net heat value in kcal/ m³
- \(\eta_{el}\) co-generator electric efficiency

**Benefit from recovered heat.** The generated kWh cost calculated as above has been deducted of the economic benefit from the machine heat recovery, which avoids the consumption of methane that should be burnt in a conventional boiler to generate the same heat amount.

Such benefit compared with the generated electric energy is calculated by the formula below:

\[
c_{gas} \beta_{rec} \frac{(\eta_{el} - \eta_{tot} - \eta_{cald} \cdot k)}{\eta_{el} \cdot \eta_{tot} \cdot \eta_{cald} \cdot k \cdot pci}
\]

where:
- \(c_{gas}\) methane gas cost in Euro/cu.mt. for industrial applications
- \(pci\) natural gas net heat value in kcal/cu.mt.
- \(\beta_{rec}\) heat recovery coefficient (actually exploited heat percent rate)
- \(\eta_{el}\) co-generator electric efficiency
- \(\eta_{tot}\) co-generator overall efficiency
- \(\eta_{cald}\) thermal efficiency of conventional - boiler
- \(k\) kcal to kWh conversion factor (k = 1,153.10⁻³ kWh/kcal)

Comparing such cost with that of the energy that would be bought from the mains, if the machine had not been installed (tariff for supply Medium Voltage for non eligible customer), the following issues was determined for a number of possible applications of a 45 kW machine:
- Pay Back Period
- Self-generated kWh cost (including the benefit for recovered heat).

**Complementary data.** The values used for the main study data are shown in Table 2.

**TABLE 2 – Complementary data**

| Natural gas net heat value (\(pci\)) | 8,250 kcal/m³. |
| Interest rate (\(i\)) | 12% |
| Natural gas cost (\(c_{gas}\)) | 0.1-0.2 Euro/ m³. |
| Boiler equivalent efficiency(\(\eta_{cald}\)) | 85% |

**ECONOMIC ASSESSMENT RESULTS**

The procedure above was applied to some possible scenarios assuming different microturbine characteristics, heat recovery, type of electric tariff,
operating time and natural gas cost. Some of the results are shown in graphic representations 1 and 2 which illustrate the interrelation of the kWh cost and the Pay Back Period with the various parameters. The figures are relevant to a case where 70% of co-generated heat is supplied back to the process.

For users with a high number of operating hours and a low natural gas cost, the Pay Back Period is of some years.

It is worth mentioning that at gas costs higher than 0.15 Euro/m$^3$, some of the Pay Back Period curves show a minimum. This trend is due to the fact that the power tariff considered for the purchase from the mains is multi-hour type (low energy price in the low load hours), so that the cost for the energy self-generated in low load hours is higher than the cost of the energy that could be bought from the mains. This makes the use of the turbine in such hours uneconomic.

**KEY RESULTS FROM TESTS**

In the frame of a wide range study activity on distributed generation started some years ago, CESI has installed in its factory a 45 kW microturbine with its own thermal load operating in parallel with the public LV mains.

This machine was tested for:

- Electric characterization under static conditions
- Electric characterization under dynamic conditions
- Noise characterization
- Gas emission characterization

The results obtained therefrom are briefly discussed herein. To provide a completely reliable and significant assessment of the machine, it is necessary for the machine to operate for a longer time.

**Electric characterization under static conditions**

The machine electric efficiency increased with an increase in the required electric capacity and decreased with an increase in the capacity as required by the thermal load. The maximum electric efficiency is 21%.

**Electric characterization under dynamic conditions**

The machine roll time is about 60 seconds.

Failing the public mains, the machine immediately stops (undesired island); this condition was also tested under very low power exchanged with mains (0.5 kW).

The machine was subjected to “voltage failures” caused in a parallel loop; the machine stopped after about 50 ms when residual voltage was about equal to 75% of rated voltage.

**Noise characterization**

Weighed sound pressure levels (dB(A)) were measured under different electric and thermal conditions. The average noise levels range from 75 to 80 dB(A). These values are slightly higher than the values admitted by the Italian standards for machines designed for residential applications. However, the limits could be complied with by acting on the sound-proof characteristics of the machine installation room.

**Gas emission characterization**

The CO and NOx emissions were measured at maximum capacity and resulted to be approximately 300 ppm and 25 ppm respectively. The fuel gas being methane, the SO$_2$ content is practically nil. The gas temperature range from 85°C to 125°C.

**Conclusions**

The application of microturbines at small-average size MV users’ was tested. A potential interest in the use of these machines was identified. The economic convenience generally depends on the machine operating time and the heat percent rate used in the local heat load. The economic advantage is strictly associated with the electricity and gas tariff structure and requires a detailed evaluation of the electric energy bills of the concerned users. The results of trials carried out on a 45 kW machine were also briefly reported. In terms of electric efficiency, the values are still lower than those of this technology trend. The noise and gas emissions would allow the use of these machines also in the residential areas by adopting some tricks. The machine needs more improvements to attain significant values and ensure global reliability.

**References**
