

A METHODOLOGY TO EVALUATE THE ECONOMIC AND ENVIRONMENTAL PARAMETERS OF THE MAIN EQUIPMENT IN A CHCP SYSTEM

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ABSTRACT: With the intention to place the University City of Rome in a vanguard position in the use of renewable and low-emission energy sources, it has been planned to subdivide the district in "islands", each characterized from different energy sources. One phase of this new energetic organization involves the installation of a trigeneration system based on a microturbine for the electric power production and an absorption chiller, fed directly from the exhaust, to supply thermal energy for the satisfaction of the winter energy requirements and of the necessities of summer air conditioning. In the paper, a methodology for the preliminary choice of the main equipment, based on the data provided in the technical descriptions of the suppliers, in order to obtain an objective "evaluation parameter", is described. The methodology could be useful to synthesize the valence of the project, not only from the economic point of view but also considering the environmental value.

Keywords: energy, cogeneration, CHCP, microturbine

1. INTRODUCTION

The rapid growth in population and industrialization, and the associated increase in energy demand and consumption, requires more and more attention in selecting environmentally compliant and efficient energy conversion systems. Subsequently, for current and future generating facilities, the traditional utility companies and the independent power producers have to face up to operational restrictions, increased efficiency requirements, variations in energy prices, concerns about future environmental legislation and the uncertainty over future utility demands. In addition, other possible

interest groups, such as universities, hospitals or general industry, who believe cogeneration to be viable for their operations, need technical assistance in determining whether a total energy system is viable for them, the options available, and the reliability of the systems. This can be very difficult when the complexities of energy, environment and economics are projected into requirements for a total energy system, i.e., fuel selection, energy conversion selection, process requirements, costs (capital, O&M, life cycle), pollution reduction/control techniques, and system integration [1].

With this multitude of design parameters, conditions and constraints, any decisions on

whether a system design meets acceptable specifications can only be made when traditional and advanced engineering analysis techniques are applied to the design problem, i.e., the total energy system is investigated, optimized thermodynamically, economically and environmentally.

The combined heat, cooling and power production (CHCP) is one of the most interesting methods to increase the system global efficiency by supplying electric and thermal power needs both in winter and in summer, [2], [3], [4].

In a CHCP system global efficiency increase is related to the use of waste heat: this can be used as input power for heat-activated air conditioners, absorption chillers, or desiccant dehumidifiers; to generate steam for space heating; and/or to provide hot water. By making use of heat energy that is normally wasted, CHCP systems can meet a building's electrical and thermal loads with a lower input of fossil fuel, yielding resource efficiencies of more than 80%. The CHCP (also called tri-generation) station is constituted by an engine (gas micro-turbine), an asynchrony generator for electric power production and a direct exhaust absorption chiller/heater for the summer and winter air conditioning systems.

2. DESCRIPTION OF THE PROJECT

A CHCP programme is planned in a specific area in the "University City" of the University of Rome "La Sapienza" (approximately 1000.000 cubic meter and an energy bill of some 10 M€) and it consists of a gas microturbine and a direct exhaust absorption chiller/heater, and will be realised in the area of the Pharmacology Institute, being the first example in Italy.

The definition of the optimal dimension of a CHCP is initially based on calculations about the economic convenience. These calculations need to analyze the electrical and thermal loads and the electricity and the

fuel costs, in order to perform an economic evaluation.

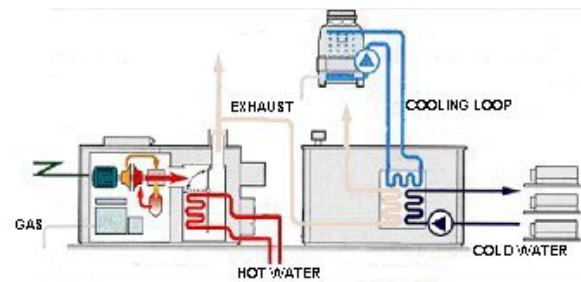


Fig. 1 – Scheme of the tri-generation plant

To verify the optimal size of the system, a simulation of the consumptions has been carried out, for the typical days of the year, week and festive, month for month. The examined configurations, make reference to various sizes of cogenerator system, each in combination with different sizes of absorption groups.

The preliminary results of the calculation have identified, with reference to the actual buildings needs and assuming an increment of the installed cooling power of 600 kWf, a gas turbine size of 80-130 kW_e, in combination with absorption groups in the range of 90-140 kWf.

3. COMPARATIVE ANALYSIS

A comparison of the microturbines available on the Italian market (Capstone, Elliot, Turbec and Bowman) [6], based exclusively on the energy, environment and set-up features, is presented. The economic feature has been also included, but it must be considered only as indicative, as the economic evaluation depends strongly on the set-up, the connection with the absorption machine and on the peculiar characteristics of the site (the indoor or outdoor installation, as an example). The data has been mainly derived from the technical descriptions of manufacturers and, if not available, estimated according to criteria explained in the notes.

3.1 Energy

Table 1 shows the energetic performances of the four systems, on the base of the information supplied from the manufacturers. The total efficiency of the system is estimated like relationship between the sum of the useful electric and thermal powers and the heat introduced by the fuel.

The microturbines can have different thermal and electrical efficiencies based on the design, developed to optimize the cost of the equipment and its performances. The microturbines typically require the gas supply to the pressure of 3.5 – 6.5 bars. The distribution gas network generally has pressures of the order of some ten or hundred of millibar and is therefore necessary a compressor of the gas. In the table therefore, the presence of the additional compressor has been considered (Systems 1 and 4), if not already integrated in the machine (Systems 2 and 3), to evaluate the net efficiency of the system.

Table 1 – Energy features

Performance	System 1	System 2	System 3	System 4
Power (kW)	65	105	100	80
Net power (kW) ¹	61	100	100	76
Gas consumption (Sm ³ /h)	25.7	37.7	34.7	29.7
Heat consumption (kW), LHV ²	226	362	333	285
Net electric eff. (%), LHV	27	27.6	30	26.7
Net electric eff. (%), HHV	24.3	24.9	27.1	24.0
Exhaust flow (kg/h)	1764	2950	2880	2848
Thermal energy (kW) ³	112	165	155	136
Thermal eff. (%), LHV	49.5	45.6	46.5	47.7
Total eff. (%), LHV	76.5	73.2	76.6	74.4
Power/Heat Ratio	0.54	0.61	0.65	0.63

¹ If the compressor is not included, a consumption of 5% of the produced power has been assumed.

² Methane lower heat value (LHV) is 9.6 kWh/Sm³ and the higher heat value (HHV) is 10.65 kWh/Sm³

³ Referred to a water temperature range from 60 to 70 °C

From Table 1 it can be evidenced that System 3, in comparison to the others, privileges the electric power production (it has the highest efficiency, 30%, and the greater Power/Heat ratio, equal to 0.65) regarding that thermal one. Given to the elevated efficiency of electrical production, the net total efficiency of the cogenerative system is however high. Also Systems 2 and 4 have high Power/Heat ratio, but the total efficiency is lower. System 1 has one good thermal efficiency and an elevated value of that total one in terms of CHP.

3.2 Environment

Microturbines are characterized from low levels of polluting emissions as they use advanced technologies of combustion (lean premixed), in order to obtain low temperatures of flame. The main polluting emissions are the nitrogen oxides (NO_x), carbon monoxide (CO) and unburned hydrocarbons (THC). Sulfur dioxide traces (SO₂) can be present in the exhausts depending on their content in the supplied fuel.

The emissions reported in Table 2 are evaluated at 100% load; in partial load conditions the values can be higher.

Table 2 – Environment

Performance	System 1	System 2	System 3	System 4
Elec. power (kW)	65	105	100	80
El. Gross eff. (%)	28.8	29	31.5	28
NO _x , (ppmv)	<5	<24	<15	<25
NO _x , (kg/MWh)	<0.12	<0.55	<0.384	<0.57
CO, (ppmv)	<40	<25	<15	<25
CO, (kg/MWh)	<0.6	<0.35	<0.216	<0.35
THC, (ppmv)	<9	<9	<10	<9
CO ₂ , (kg/MWh)	735	668	615	690

System 1 is characterized by the lowest guaranteed value of emissions of NO_x in full load. The emissions of CO and THC measured in documented tests from the manufacturer are lower (5 ppm and 1 ppm respective) of those reported in the table as guaranteed values. The low electrical

efficiency of the equipment determines the highest value for CO₂ emissions. From the point of view of the emissions System 3 is ranked immediately after System 1, with low guaranteed values of emissions and lower emission of CO₂ for electrical MWh produced, given the high efficiency that characterizes the microturbine.

3.3 Set-up

About the set-up and installation, the following factors have been considered: dimensions, weight, noise, presence of the compressor integrated in the machine.

Table 3 – Set-up

Prestazioni	Syst. 1	Syst. 2	Syst. 3	Syst. 4
Length (mm)	1956	3000	3652	3100
Width (mm)	762	840	900	876
Height (mm)	2388	2110	1810	1922
Volume/Power (litri/kW)	54.7	50.6	56.6	65.2
Weight (kg)	1364	2000	2750	1930
Specific weight (kg/kW)	21	19	26	24
Noise (dbA)@1m	83 ⁴	<75	70	70
Compressor	NO	SI	SI	NO

From Table 3 the more compact machine (minor specific weight and volume) is the System 2, followed from System 1 that, however, does not include the compressor inside. System 3 appears quite large and heavy, because of the high efficiency regenerator and of the CHP exchanger, than in practical it is an additional module applied to the microturbine. The Systems 3 and 4, in their sound-proof configuration, have the best performances related to the noise level, while System 1, with 65 dbA at 10 meters, is the noisier equipment, without to hold account of the fact that the compressor is not included in this noise level.

3.4 Economics

A preliminary estimation of the costs associated to the set-up of the microturbine in CHP configuration, comprehensive of

switchboard, compressor and control software is summarized. The costs of the equipment have been estimated following some indications of the manufacturers. To these costs, the following have also been added: infrastructural and materials for the connections, assumed to contribute for 40% of the costs of the equipment; engineering for integration of the system to the existing net, 8%; uncertainties, 5%. Table 4 shows therefore the economic evaluation, (consider it as indicative as subjected to uncertainties due to the effective installation conditions). All the costs are for unit of produced net power and with reference to one configuration "grid connect" (connection in parallel to the electric network).

Table 4 – Economics

Costs (Euro/kWe net)	Syst. 1	Syst. 2	Syst. 3	Syst. 4
Microturbina	1197	1150	1140	1200
Compressor	90	Incluso	Incluso	90
Switchboard	105	80	80	80
Control Software	50	65	60	50
TOTAL Equipments	1442	1295	1280	1420
Working and materials (40%)	577	518	512	568
Engineering (8%)	115	104	102	103
Uncertainties (5%)	72	66	65	71
Total cost	2206	1983	1959	2162

3.5 Final evaluation

In order to perform an objective evaluation of the different equipments, a merit index is needed to synthetize the value of different choices, from the technical, economic and environmental points of view. The four main features have been considered: Energy (EN), Environment (EV), Set-up (SU), Economics (EC). Since there are different features to be considered and, for each aspect different characterizing parameters are present, it could be useful a normalization of the scale defining the various parameters, using maximum or minimum values (according to the best

⁴ Estimated from 65 dbA at 10 m declared by the manufacturer

condition) that such values can assume; the procedure could be carried out as:

$$PM_i = ((G - G_{min}) / (G_{max} - G_{min})) * 90 + 10$$

in case higher value has to be assigned to maximum values (as an example, the efficiency) and

$$PM_i = ((G_{max} - G) / (G_{max} - G_{min})) * 90 + 10$$

if a minimal value is considered the best condition (the emissions and the noise). In both these cases the better values will be credited with an evaluation parameter of 100 and the worst with a value of 10.

Using these normalized values, it is possible to carry out elaborations aimed at obtaining an overall evaluation parameter, based on the ranking of the single parameters and the single feature. The different parameters in a single aspect, if more than one, are added (with an equal weight) in order to obtain the parameter of evaluation (therefore equal to the average value of those of the single parameters) relative to each of the four features considered (energy, environment, set-up, economics). The parameters considered will be:

- Energy:
 - Net electric efficiency*
 - Thermal efficiency*
- Environment
 - Emission of NO_x in kg/MWh*
 - Emission of CO₂ in kg/MWh*
- Set-up:
 - Weight to Power ratio*
 - Volume to Power ratio*
 - Noise*
 - Compressor of the gas (the maximum value if included, minimal if external)*
- Economics:
 - Cost of investment*

The total evaluation parameter will be the following:

$$PM = K_{EN} PM_{EN} + K_{EV} PM_{EV} +$$

$$+ K_{SU} PM_{SU} + K_{EC} PM_{EC}$$

In the present comparative evaluation of the various solutions, have been used, as an example, the following values:

$$K_{EN} = 1.1; K_{EV} = 1.25; K_{SU} = 0.9; K_{EC} = 0.75$$

by which an higher importance is attributed to the environment and energy features.

Table 5 – Final comparison

Feature	K	PARAM.	Sys. 1	Sys. 2	Sys. 3	Sys. 4
ENERGY	1.1	Net el. eff (%), PCI	18.18	34.55	100.00	10.00
		Therm. eff (%), PCI	100.00	10.00	30.77	58.46
		PM _{EA}	59.09	22.27	65.38	34.23
ENVIRONMENT	1.25	NO _x , (kg/MWh)	100.00	14.00	47.20	10.00
		CO ₂ , (kg/MWh)	10.00	60.25	100.00	43.75
		PM _{PA}	55.00	37.13	73.60	26.88
SET-UP	0.9	Volume/Power (liters/kW)	74.73	100.00	63.01	10.00
		Sp. weight (kg/kW)	74.29	100.00	10.00	35.71
		Noise (dbA)@1m	10.00	65.38	100.00	100.00
		Compressor	10.00	100.00	100.00	10.00
		PM _{IA}	42.25	91.35	68.25	38.93
ECONOMICS	0.75	Total cost (Euro/kWe)	10.00	91.26	100.00	30.40
		PM _{FA}	10.00	91.26	100.00	30.40
TOTAL		PM	179.28	221.56	300.35	129.08

The overall evaluation parameter, therefore, will assume values in the range 40 - 400. Based on the above considerations, Table 5 is obtained. From the table is obtained that the System 3 presents the best average characteristics in all the features and in the total ranking (PM = 300.35), followed from System 2.

Note that the parameter relative to the CO₂ production could be eliminated from this analysis considering that: a) carbon dioxide produced is function of the gross electrical efficiency, partially already held in consideration into the energetic aspect

where the net efficiency is present; b) the produced carbon dioxide, due to the low content of other polluting ones in the exhaust, could become an added value of the plant for the possibility to use it partially in greenhouses and of keep the excess for similar uses.

Moreover, a total evaluation for the final selection of the equipment, must necessarily include, beyond to the defined evaluation parameter, other features as the support provided by the manufacturer in phase of installation and start-up, the reliability of the equipment and the maintenance costs, the availability of the manufacturer to cooperate in research and development activity and other parameters that need to be considered in a further step of the analysis.

4. CONCLUSIONS

The City University "La Sapienza" is a small district of Rome, but it can assume a remarkable symbolic impact and of sensibility promotion due to the importance of the Institution that covers the area, becoming expression of a new sensibility regarding the environment, through a rational use of the energy. With the intention to place the university City in a vanguard position in the use of renewable and low-emission energy sources, it has been decided to subdivide the district in "islands", each characterized from different energy sources. The first stage of this energy new organization involves the buildings of Pharmacology, for which it has been decided to install a system of tri-generation constituted by a microturbine for the electric power production and by an absorption chiller, fed directly from the exhausts, to supply thermal energy both for the satisfaction of the winter and summer energy requirements for air conditioning.

A methodology for the preliminary choice of the main equipment, based on the data provided in the technical descriptions of the suppliers, in order to obtain an objective "evaluation parameter", has been described. The methodology could be useful to synthetize the valence of the project, not only from the economic point of view but also considering the environmental value.

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