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Performance prediction of micro-CHP systems using simple virtual operating cycles

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HIGHLIGHTS

- A methodology to estimate in advance actual performance of micro-CHP systems is given.
- A Virtual Operating Cycle is introduced for the micro-CHP system.
- Limited information on the micro-CHP from manufacturer is used.
- Procedure can be used for fast estimation of energy and environmental performance.
- Application to residential user is described.

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ABSTRACT

This paper presents a general methodology to roughly estimate in advance the actual performance of μ-CHP (micro Combined Heat and Power) systems in one year of operation, by means of limited information on the CHP prime mover efficiency and emission factors in selected set points and by means of a simplified prediction model of the operating cycle. The carried out analysis has been applied to several market-available and under development μ-CHP units of different technologies (Internal Combustion Engines, Micro Gas Turbines, Organic Rankine Cycles, Stirling, Thermo Photo Voltaic, Fuel Cell), operated under a hypothetical virtual operating cycle. The virtual cycle is obtained in this paper on the basis of the year thermal demand of a domestic user, assuming thermal load following of the CHP system. The methodology can be generalized to different applications and different management logics of the CHP system.

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1. Introduction

Cogeneration, i.e., Combined Heat and Power (CHP) generation, is a viable strategy often promoted [1] as one of the most promising available solutions for energy saving and emission reduction [2]. Micro-CHP systems, i.e. generators with nameplate electric power output roughly below 100 kW and more often in the range 1–10 kW, are under investigation in many industrialized and developing countries, mostly as potential substitute of domestic boilers or in isolated applications.

The issue of μ-CHP performance assessment is of great importance (examples of performance characterization can be found in Refs. [3,4]), especially considering new machines based on not-fully-developed or less consolidated technologies and with regard to the local regulations, as highlighted by Peacock et al. in Ref. [5]. The available/under development technologies in this sector (review of the current technology can be found in Refs. [6,7] and in Ref. [8] analyzing Energy, Economic and Environmental implications) are small Internal Combustion Engines (ICE), Micro Gas Turbines (MGT), Micro Rankine Cycles (MRC), Stirling Engines (SE) Fuel Cells (FC) systems and Thermo Photo Voltaic (TPV) generators; these systems do not have an equal level of technological development or maturity (see Refs. [9,10] for FC μ-CHP performance data and [11] for TPV prototype application). A large market potential for Micro-CHP has been identified since more than ten years ago, as highlighted for example by Dentice d'Accadia et al. in Refs. [12], but local, regional and international regulations on CHP requiring a detailed experimental monitoring of CHP systems (e.g. the national Italian and European rules on "high-efficiency" CHP require to fulfill some prescriptions, which inevitably lead to measurements on the thermal & electric production) can be a barrier to the diffusion in small scale applications.

The measurement of CHP systems actual performance and the consequent merit qualification, highlighted for example by

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Verbruggen in Ref. [13], is more complicated in case of μ-CHP systems, where on-site performance monitoring and acquisition systems are not easily installable in a cost-effective way.

In such a scenario, a viable strategy to pursue could be to approximate in advance the actual operation with virtual simple operating cycles, in order to predict the realistic energy/environmental and also economic performance of a μ-CHP system defining a standardized, simplified, fast and cost effective procedure.

2. Micro-CHP nameplate and part-load performance data trends

Micro-CHP performance data are usually provided by manufacturers taking as reference base load operation; for example Fig. 1 reports data of electric efficiency thermal efficiency and NOx emissions collected by the authors in previous studies [2,14], referring to various commercial CHP and μ-CHP systems. Depending on the system technology and electric size, the nameplate electric efficiency can range in between 10 and 30% and the thermal efficiency at maximum recovered thermal power is in between 40% and around 90%. Specific emissions at full power are significantly affected by the Micro-CHP technology (see Fig. 1 referring to NOx and CO) and for a given μ-CHP kind, they are roughly decreasing with electric efficiency.

Micro-CHP systems have natural potential suitability for different civil, tertiary and industrial applications (see few application studies in Refs. [5,15–23]), such as residential buildings, hospitals, supermarkets, sporting centers, etc., where a significant thermal and cooling demand is associated to the user electricity demand. In such various applications, it is common to observe time-varying electric and thermal energy demand. The actual energy/environment performance of the μ-CHP systems can be significantly affected by the operating cycle, which is difficult to predict in details before the CHP system is installed.

Moreover, the economic convenience of CHP systems strongly depends on the specific application scenario in which the CHP system operates, as pointed out in previous studies of the authors [14,15] and others [21–25]. Nevertheless, very limited data on the forecasted operating sequence of the μ-CHP over the year can be available in many practical cases.

Significant variations in the CHP performance occur at part load conditions, in comparison with base load conditions, as shown in Fig. 2a and b reporting, as examples, normalized electric and thermal efficiency plots versus the normalized electric load, for three different CHP systems (namely Capstone C30 MGT is CHP1 in Fig. 2, Caterpillar G3306NA ICE is CHP3 and Turbec 100 MGT is CHP2 [26–28]). Moreover, also pollutant emissions are largely affected by part-load conditions, as provided in Fig. 2c and d, presenting NOx and CO specific emission trends per unit of output electric power, for four CHP systems, namely two ICEs (Cat G3306NA is CHP6, AVL is CHP4) and two MGTs (Elliot TA80 is CHP 5, Garrett GTP-30-67 is CHP7), according to Refs. [26,29–31]. The electric efficiency plots are increasing with power and the thermal efficiency is decreasing, for all the considered prime mover; on the contrary, the gas emission data trend can be increasing or decreasing versus load depending on the specific prime mover model. The shown performance quantities are strongly dependent on the load, with changes in NOx and CO of various orders of magnitude moving from full load to minimum load.

Thus, the limited but representative number of provided trends, concerning energy/environmental performance of selected μ-CHP systems, is clearly indicating the need to take into account the actual load occurrence in specific applications, including definitely part loads, in order to correctly predict the overall yearly primary energy consumption and pollutants production.

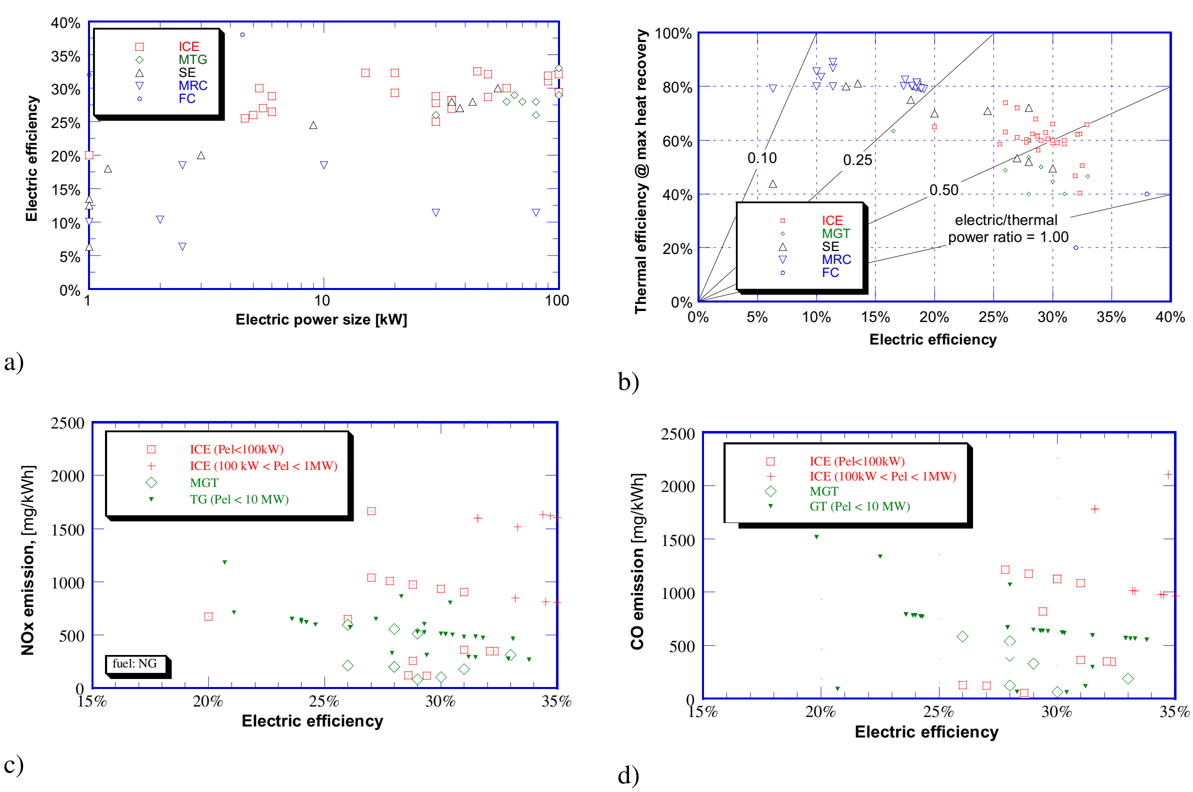

Fig. 1. Base load micro-CHP nominal performance data: a) electric efficiency vs size; b) thermal efficiency vs electric efficiency; c) NOx and d) CO emissions, for selected CHP systems.

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