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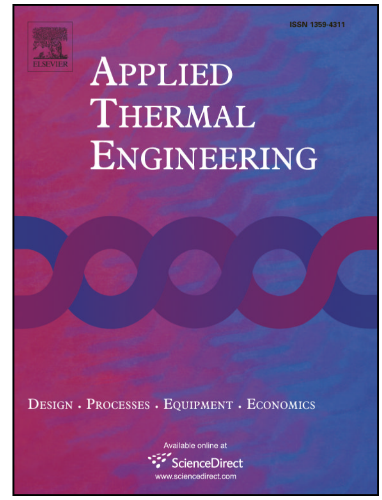

Research Paper

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Alfredo Gimelli, Raniero Sannino

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A multi-variable multi-objective methodology for experimental data and thermodynamic analysis validation: an application to micro gas turbines

Alfredo Gimelli[a], Raniero Sannino[a*]
[a]*Department of Industrial Engineering, University of Naples Federico II, Naples, Italy*

Abstract

A methodology aimed at defining thermodynamic model parameters and validating experimental data has been proposed. The methodology consists of a thermodynamic model of a micro gas turbine coupled with a multi-variable multi-objective genetic optimization algorithm, in which decision variables and objectives are set depending on available experimental data. To validate both the thermodynamic model and the collected experimental data, the methodology has been applied to two micro gas turbine plants: the Capstone C30 and the Turbec T100. Validations of the thermodynamic model and the collected experimental data for the two plants have been performed by evaluating the match between input and output physical parameters. The optimal results of the optimization algorithm have plausible thermodynamic parameters and constitute the Pareto front; between these results, the one with the minimum difference between experimental data and calculated values is chosen as preferred. The two studied cases highlight the effect of measurement chain errors on experimental data reliability: the greater is the overall variance of the objectives, the lower is the accuracy of the experimental data. The effectiveness of proposed methodology has been verified for the Capstone C30 through the congruence of the design operating conditions on both the compressor and turbine maps.

Keywords: Experimental validation, Micro gas turbine, Multi-objective optimization, Thermodynamic analysis, measurement reliability

1 Introduction

World climate change and global warming increase are two urgent and strategic issues that national and international governments have to face; different scenarios aimed to estimate the world energy demand were realized by IEA [1], and each scenario distinguishes itself by energy policies over the years. In order to keep the temperature increase below 2°C above pre-industrial level, two challenging targets must be achieved: improvement of renewable energy exploitation and reduction of final energy consumption. Despite small-scale energy conversion systems [2]-[5] are able to efficiently achieve these targets, their design must be based on reliable and congruent system models to evaluate the plant performances. In particular, micro gas turbine (MGT) plant development had a boost in the middle of the twentieth century, owing to their application in automotive and energy markets [6]; the most significant advantages of these small-sized turbomachines are their compact size, low maintenance requirements, low NO_x emissions, and fuel flexibility [6],[7]. Nowadays, they are also suitable for household use [8],[9] for power generation and for cogeneration application, owing to their low noise and vibration production [10]. Moreover, in the last few decades, many thermodynamic analyses have been performed on energetic plants based on micro gas turbine technology, i.e., coupled with an absorption chiller [11] or with concentrated solar power [12]-[14] or retrofitted for wet operation [15]. In [16], a thermal cycle analysis and thermochemical equilibrium evaluation was performed and an operating domain definition was obtained by using component-matching analysis; the authors of [17] focused on the thermoeconomic analysis of regenerated and intercooled recuperative cycles.

All these works highlight the relevance of the potential of micro gas turbines, even concerning their integration with renewable energy sources, as well as the key role of performing thermodynamic analysis on these systems; in fact, these references support the authors' great interest in performing thermodynamic analysis aimed at designing and controlling micro gas turbine plants, such as already has been done by others: in [18], a thermodynamic analysis has been performed on standard and innovative micro gas turbine cycles along with the modeling of greenhouse gas capture unit, while in [19] a micro gas turbine with post-combustion capture plant has been investigated through thermodynamic analysis. However, to represent an acceptable and validated model of the physical system, a thermodynamic model must be carefully calibrated, as detailed in [18] and [20]; calibration, in turn, needs a wide experimental campaign to define the model parameters and constraints, because of the uncertain and indeterminable measurement errors [21]. In particular, MGT control models require many operating points of experimental data, which means, as stated above, several tests for each point. A long and onerous effort then follows to determine the reliability of the models, as stated in [22] about two model predictive controllers for engine speed regulation.

Most of published works concerning energy conversion systems focus their studies on the optimization of both specific components design (e.g., inlet guide vane position in a heavy-duty gas turbine in [23] and compact heat exchanger in a methanation plant in [24]) and whole plant management, such as MGT based CHP [25], MGT integrated

[*]Corresponding author: raniero.sannino@unina.it; Via Claudio 21, 80125 Napoli, Italy.