Retrofitting micro gas turbines for wet operation.

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Long Abstract

Introduction

It is generally accepted that only flexible CHP plants could be a viable option in an electrical system with high penetration of variable renewables. Variable power-to-heat-ratios and decoupled power and heat generation will be basic requirements. Currently, the most common way to fulfill these specifications is the use of heat storage devices, whereas wet operation of gas turbines is an alternative way to achieve both goals.

There are many parameters affecting the technical and economic performance of decentralized CHP plants, apart from its technical characteristics. Their operational strategy, the specific consumer characteristics and the energy market conditions are some of the most crucial of them. Most decentralized CHP plants are boiler replacement facilities covering the consumer heat demand and producing electricity in parallel. This task alone does not require flexible operation since the produced electricity can be fed into the grid. However, the concurrency of wind generation and heat demand and the ever expanding penetration of variable renewables will force regulators to introduce limits in the amount of CHP power that electric networks will absorb. As a result of this operational frame, CHP plants will be forced to operate in a much more flexible way and most probably decouple power and heat production.

Heat storage has been proposed as a potential solution to this problem despite the additional costs and storage space requirements. An alternative way to introduce the aspired flexibility in micro gas turbine CHP plants would be to adapt them and enable their wet operation. At low heat loads, excess exhaust heat is used to produce steam, which is in turn injected into the combustion chamber to increase the electrical efficiency of the turbine. A variable power-to-heat ratio is simultaneously achieved and the turbine can still operate at full electric load, while covering lower heat loads.

The current work is an analysis of micro gas turbines adapted to operate with steam injection. A thermodynamic model is developed and two typical consumer cases, an apartments building in Berlin, Germany and a public building in London, UK are chosen as case studies. The study presumes the existence of a micro gas turbine and analyzes the results of its adaptation for wet operation. The environmental and economic performance of the new system is compared to that of its commercial counterpart. The influence of the consumer demand-profiles on the profitability of the retrofit is analyzed. It is shown, that wet combustion in mGT CHP plants makes more sense in the cases where a minimal thermal load is guaranteed throughout the whole year.

1. Methods

The modeling of micro gas turbines performance in CHP applications has been the topic of many investigations. Many debates where based on models of these plants, with a typical example being the analysis performed by Kaiko et al.[1], [2], who presented a thermodynamic and economic model for recuperated and not recuperated micro gas turbines. Interestingly their study concluded that the use of a recuperator did not make sense economically for the application in question, mainly due to the higher power to heat ratio of the resulting CHP system. However, the current developments in the European CHP market lead to an increasing demand for plants with high power to heat ratios.

This fact motivated the theoretical and experimental investigations of Delattin et al.[3] and De Paepe et al.[4] on steam injection in the Turbec T-100. Although the work of Delattin et al. [3] included an economic evaluation of wet mGT operation, this was not its focus and the results are not necessarily reliable.

In this context this work aims to achieve clarity on the economic performance of wet mGT cycles for two important cases of cogeneration applications. At this end, a thermodynamic model for micro gas turbines (mGTs) is developed based on the aforementioned works on the Turbec T-100. The part and full load operation of dry and wet recuperated mGTs is analyzed with this model. The results are used to compare the techno-economic and environmental performance of a conventional micro gas turbine and its retrofitted configuration for wet operation.

The paper focuses on two case studies of an apartments building in Berlin and a public building in London, UK. It is presumed that the existing conventional micro gas turbine was optimally sized for heat oriented operation with the respective heat and power load duration curves. The load duration curves for both buildings are available for time intervals of 15 and 30 minutes respectively. This allows the detailed simulation of the operation for each version of the turbine and each case study. A retrofit for wet operation is then assumed and the detailed operational behavior of dry and wet plants is compared both on a technical and economic level. The German CHP market is chosen as a model market environment for the study, because the electricity and heat pricing in this market are substantially simplified and allow for a thorough analysis of the economic without the need for many assumptions on the pricing of electricity and heat.

Furthermore, the advantages and drawbacks of wet operation are highlighted by its comparison to the typical heat-driven operation of dry-cycle mGTs, with a reference to the two case studies. It is shown that the wet cycle turbines have a higher number of full load equivalent operating hours and can achieve higher investment rates of return, with minor drawbacks to their overall environmental performance. In conclusion, it is shown that a minimum heat load over the whole year has an important impact on the economics of a retrofit for wet operation.

References

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[3] F. Delattin, S. Bram, S. Knoops, and J. De Ruyck, “Effects of steam injection on microturbine efficiency and performance,” Energy, vol. 33, no. 2, pp. 241–247, Feb. 2008.

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