Economic Dispatch and Unit Commitment of a Single Micro-Gas Turbine Under CHP Operation

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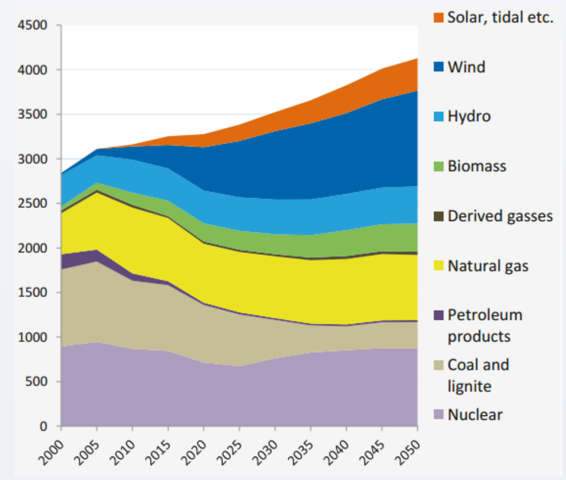
Motivation

Current energy trends forecast a dramatic increase in the global demand for energy supply. This demand will be met by increasing the use of natural gas for power generation, and will primarily be accommodated by gas turbines in combined cycle forms. Micro-turbines offer many advantages compared to other technologies including high power-to weight ratios, low terrain footprint, reliability, and lower greenhouse gas emissions.



EU electricity generation trends

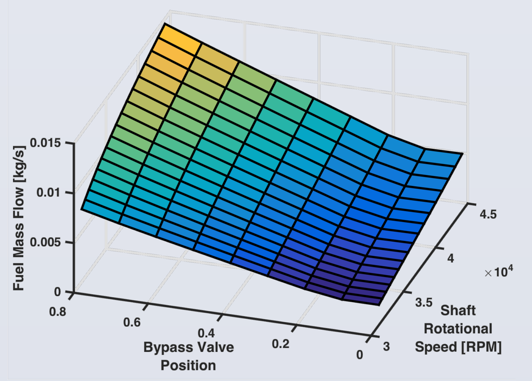
(taken from *"EU Energy, Transmission, and GHG Emissions: Trends to 2050 – Reference Scenario 2013"*)

This work considers the economic dispatch and unit commitment of a single micro-gas turbine (MGT) under combined heat and power (CHP) operation. The main contributions of this study are

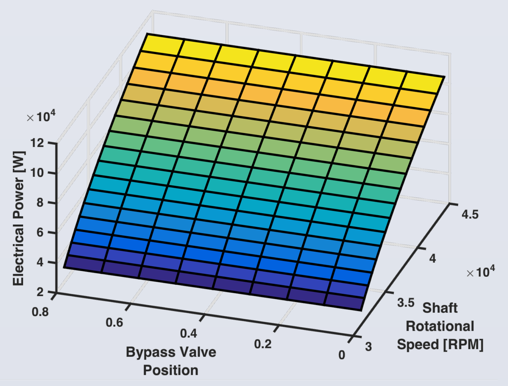
- **Modelling of an MGT** – detailed thermodynamic cycle analysis
- **Economic dispatch of an MGT** – optimization model for the operation of the MGT in the grid
- **Detailed Cases Studies** – demonstrating the advantages of MGTs for combined heating and power production

MGT Modelling and Economic Dispatch

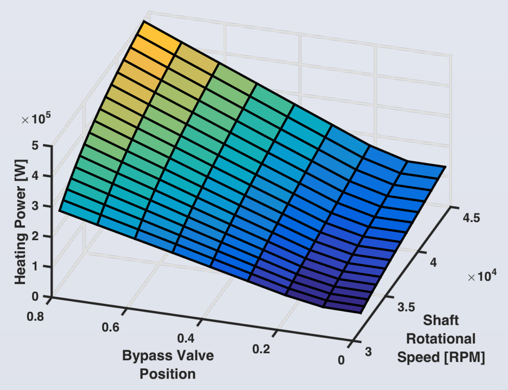
Previous efforts related to the economic dispatch for MGTs considered only the electro-mechanical response of a generic turbine, disregarding the energy conservation laws of individual components. In this work, we developed a component-based gas turbine model to describe its steady state operation. We included two input parameters - the shaft speed and bypass valve positions. Our simulation model mapped these inputs to the MGT electrical power output, heat output, and fuel mass flow. These maps are shown below.



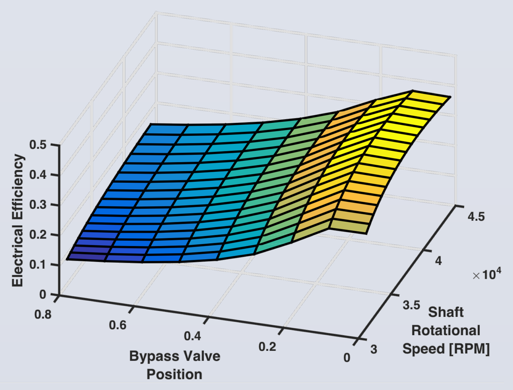
Fuel Mass Flow



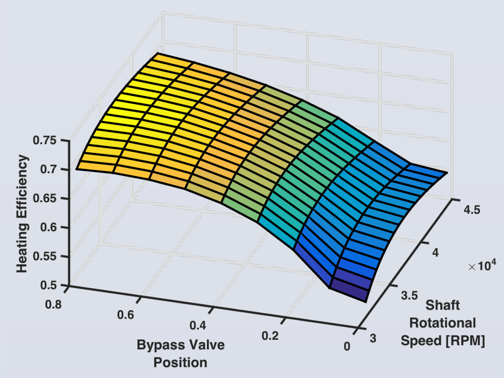
Electricity Output



Heat Output



Electricity Efficiency



Heat Efficiency

This model leads to a realistic analysis for integration of MGTs into a power generation system. The steady-state input-output maps of the MGT were used to develop a detailed optimization scheme for solving the economic dispatch and unit commitment problems. We operated the MGT as a CHP unit thereby optimizing the MGT operation to provide both electricity and heat to the user. Excess electricity can be sold back to the grid, while excess heat is simply dumped into the atmosphere. The complete optimization model described below:

$$\min_{x_{GT},u_{GT},x^P_{UT},x^H_{UT}} \quad J(x_{GT},u_{GT},x^P_{UT},x^H_{UT})$$

subject to

$$\begin{aligned}
&\texttt{(MGT Dynamics)} && x_{GT}(t+c\Delta T) = f_{GT}(x_{GT}(t),u_{GT}(t)),\\
&\texttt{(Power Balance)} && P_{GT}(x_{GT}(t)) + (x^P_{UT}(t) - P(t)) = 0,\\
&\texttt{(Heat Balance)} && H_{GT}(x_{GT}(t)) + (x^H_{UT}(t) - H(t)) = 0,\\
& && x_{GT}(t) \in \{(p_i(t),h_j(t)),\ i=1,\ldots,\mathtt{s}, j=1,\ldots,\mathtt{v}\}\\
& && x^P_{UT}(t) \geq 0,\ x^H_{UT}(t) \geq 0,\ t=1,\ldots,T.
\end{aligned}$$

The optimization model was solved using a shortest-path algorithm. Demand data for case studies were taken from the U.S. Department of Energy (2004), along with information on electricity tariffs.

Acknowledgments

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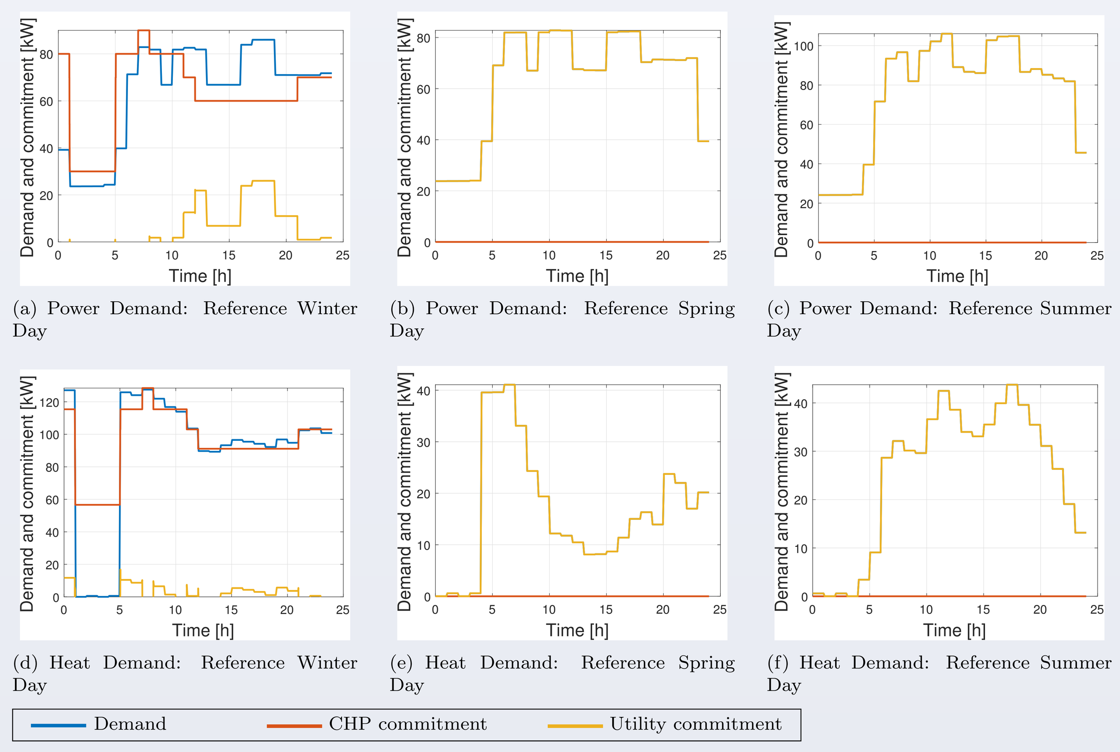
Case Studies

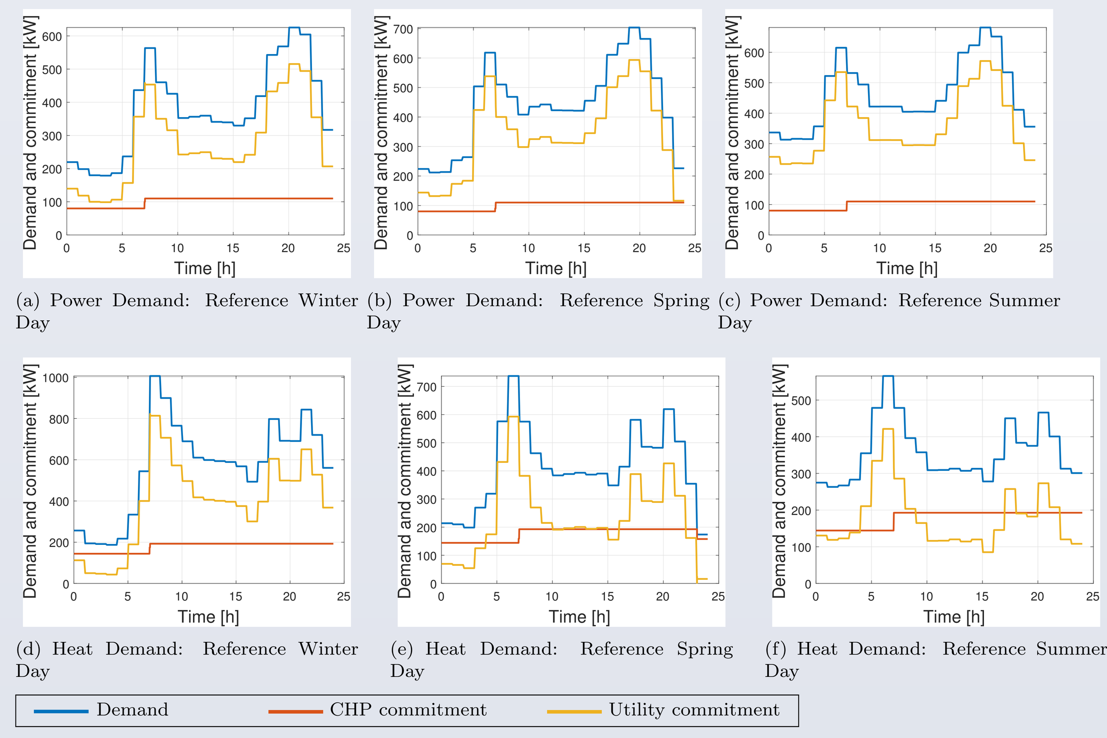
To demonstrate the benefit of integrating a single micro gas turbine into the electricity market, we provide four detailed case studies: a **full-service restaurant**, a **large hotel**, a **residential building neighborhood** and a **small hotel**. We solved the economic dispatch problem for these buildings on 3 representative days (winter, summer, spring/autumn).



Full Service Restaurant

During winter, MGT is operated on a *heat driven basis*. Electricity production is a byproduct of meeting the heat demand.

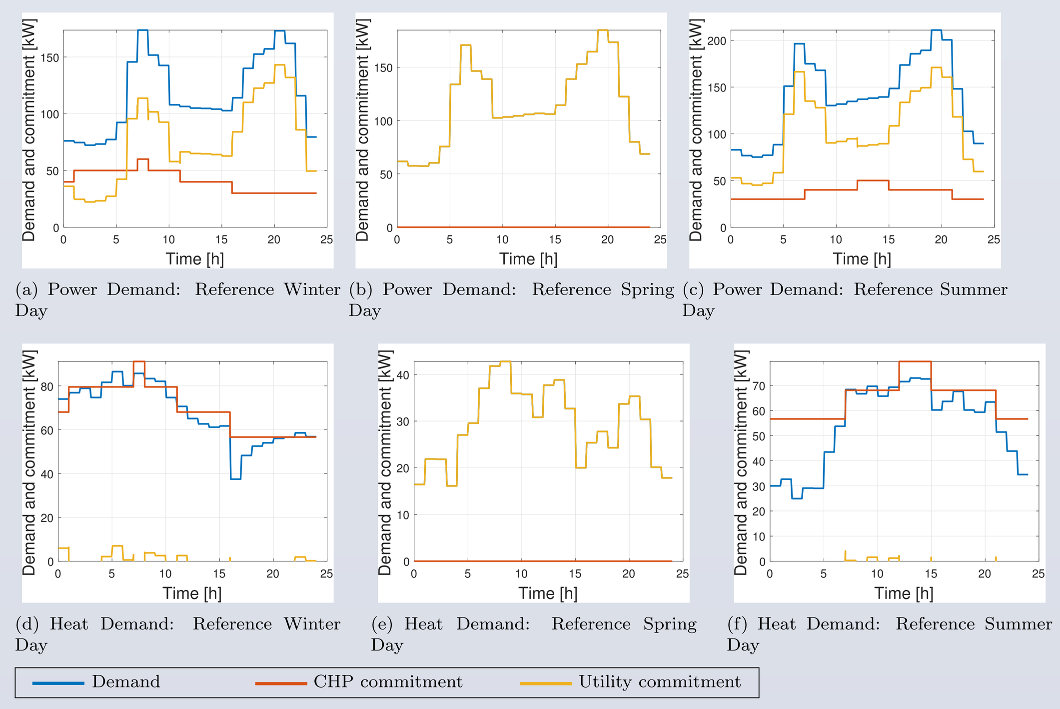
In Summer and Spring, the MGT operates on a *maintenance driven* basis. The startup/shutdown costs are too high to cycle the MGT even during intervals of high heat demand or increased utility pricing.



Large Hotel

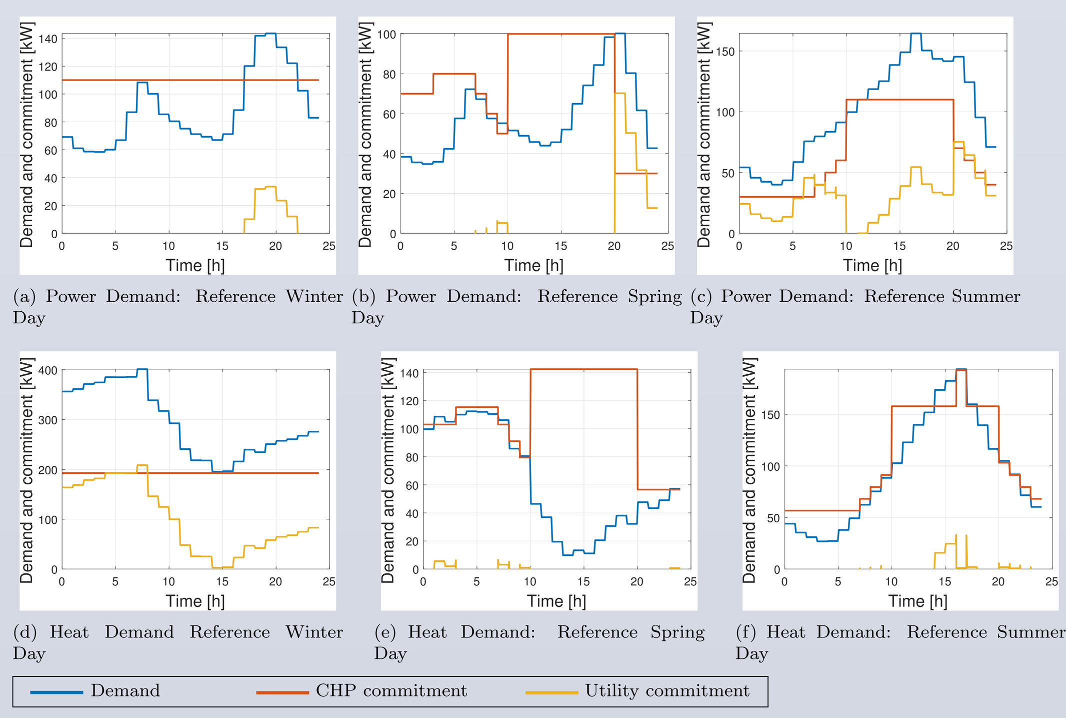
The power demand of the large hotel exceeds the maximum capacity of the MGT. The optimal commitment requires contributions from both the MGT and the utility.

The MGT consistently operates at the highest electricity production, resulting in an *Electricity Driven* operation.



Small Hotel

The MGT operates at a low power commitment level, while the heat demand is supplied at a competitive unit efficiency. This is a *heat driven* operation. During off-peak hours in the summer, the MGT is operated in a *maintenance driven* mode to avoid incurring additional startup/shutdown costs.



Residential Community

During the spring day, the MGT operates in a *revenue driven* mode. In intermediate tariff hours of the day, the MGT generates electricity and heat significantly above the demand, selling the power back to the grid. This takes advantage of the higher electricity rates during this period. During off-peak hours, the MGT demonstrates electricity driven, heat driven, and maintenance cost driven operation.

Conclusions

A comprehensive micro-gas turbine model was established for the purpose of optimizing the operational behavior of a CHP unit in a smart-grid environment. The unit commitment problem was then solved for four different consumers. Of main interest is the observation that the optimal solution results in four distinct MGT operation modes: **electricity driven, heat driven, maintenance cost driven,** and **revenue driven.**

References

J. F. Rist, M. F. Dias, D. Zelazo, B. Cukurel, and M. Palman, "*Economic Dispatch of a Single Micro-Gas Turbine Under CHP Operation*," Applied Energy, 2017 (*submitted*).