Titre:

The CFD design and optimisation of a compressor, combustor and turbine system towards a 100 kW_e hydrogen fuelled micro gas turbine

Résumé:

Within the context of an ever-increasing share of wind and solar power, the need to store energy from short to long term to balance out the power grid will become more important in the near future. Energy storage for both mid- and long term, is most feasible by using excess, and otherwise wasted, electricity (e.g., strong wind on a public holiday) for electrolysis to produce green hydrogen. Instead of then using this hydrogen to generate electricity in a conventional, large, power plant, a more efficient route is to use it in a Decentralised Energy System (DES). In a DES, the green hydrogen can be converted into electricity and heat in a Combined Heat and Power (CHP) system by using 3 different technologies: Reciprocating Internal Combustion Engines (RICE), micro Gas Turbines (mGT) or Fuel Cells (FC). In DES applications, diesel gensets (RICE) are currently the most widely used option. However, mGTs have a few distinct advantages when compared to RICEs, namely a lower maintenance cost, possibility for multi-fuel applications and opportunities for lower emissions (especially NO_x). When it comes to the comparison with FCs, mGTs are advantageous in many ways; they have a much higher power density, a far longer service life, the combustion process requires a less high hydrogen quality and they do not require nearly as much rare earth metals. However, the main disadvantage of mGTs compared to both RICEs and FCs is their lower electrical efficiency. A 100 kWe FC unit can achieve an electrical efficiency of 50%, a RICE can reach up to 35%, while a current natural gas-burning mGT with the same power output only achieves 30%. This explains their small market share in the small-scale CHP market. An obvious solution to this efficiency problem, is running the mGT at a higher Turbine Inlet Temperature (TIT), to increase its electrical efficiency.

In order to reach the goal of a 100 kW_e hydrogen fuelled mGT with a higher efficiency, such that it can compete with its RICE alternative, this work covers the design and optimisation of the combustor, compressor and turbine. This resulted in the development of a design method for a 100% hydrogen fuelled micromix type combustion chamber; both the primary and secondary zones. In addition, the impact of the air/fuel momentum ratio, the equivalence ratio and several precisely defined geometric parameters on the primary zone flame structure, NO_x emissions and temperature of the micromix were added to the literature. For the turbomachinery, a 1D design script was developed for the quick and accurate sizing of any type of radial compressor or turbine. In addition to this, a steady RANS method for performance map generation with a minimal amount of CFD simulations is detailed in this work. The 1D design script, parameterised CAD files and steady RANS method for performance map generation came together in the mGT cycle analysis and optimisation for TIT, electrical efficiency and operating range. The final result of which is a new, detailed design and cost estimate for both the complete compressor and turbine sections of a 100 kW_e mGT with a TIT of 1125°C and an electrical efficiency of 35.16%.