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Environmental condition impact on performance of micro gas turbine cycles

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Objectives

- Ambient condition impact on microturbine performance
- Performance of mGT versus ICE at part load
- Ambient condition impact on mGT fuel cell hybrid systems
- Hints on innovative micro-turbomachinery for energy harvesting

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Motivations and Background

MOTIVATIONS

- Characterization of engine with respect to ambient conditions for PUMP-HEAT H2020 EU Project
- Experimental analysis of microgas turbine based on years of field data
- Focus on impact that ambient temperature has on performance

BACKGROUND

- Analysis based on inlet temperature available at simulation level in different literature works (e.g. Caresana et al. , 2014, simulated the impact of the ambient temperature in details)
- An experimental analysis has been carried out at the Innovative Energy System Laboratory (IES Lab), TPG-DIME, Genoa, Italy, on a dedicated modified rig by Ferrari et al. In 2016

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Background analysis

- Two works are considered as reference
- They are both focused on the same engine i.e. Turbec T100 CHP

1 – Ferrari M.L., Traverso A., Massardo A.F., 2016, "Smart polygeneration grids: experimental performance curves of different prime movers", Applied Energy, vol. 162, pp 622-630.

2 – Caresana F., Pelagalli L., Comodi G., Renzi M., 2014, "Microturbogas cogeneration systems for distributed generation: effects of ambient temperature on global performance and components", Applied Energy, vol. 124, pp. 17-27.

- They introduce different correction curves due to ambient temperature
- In both cases the humidity is neglected
- Focus on electric power, thermal power, fuel consumption and efficiency

Background analysis

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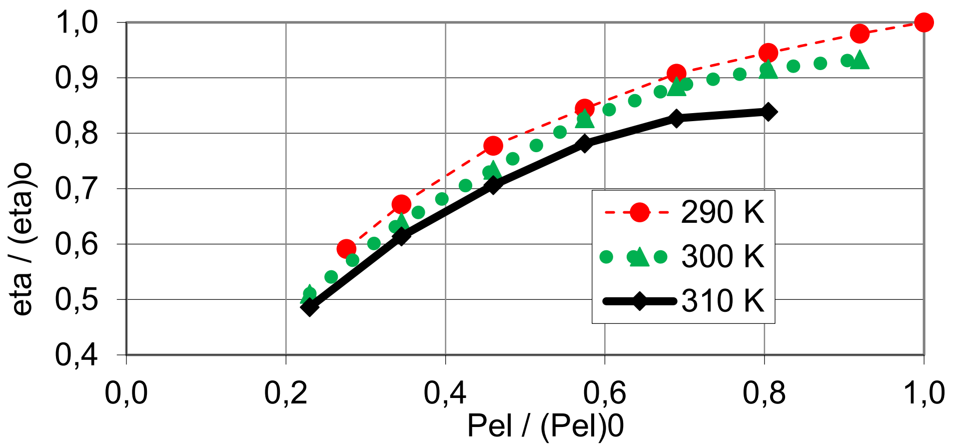
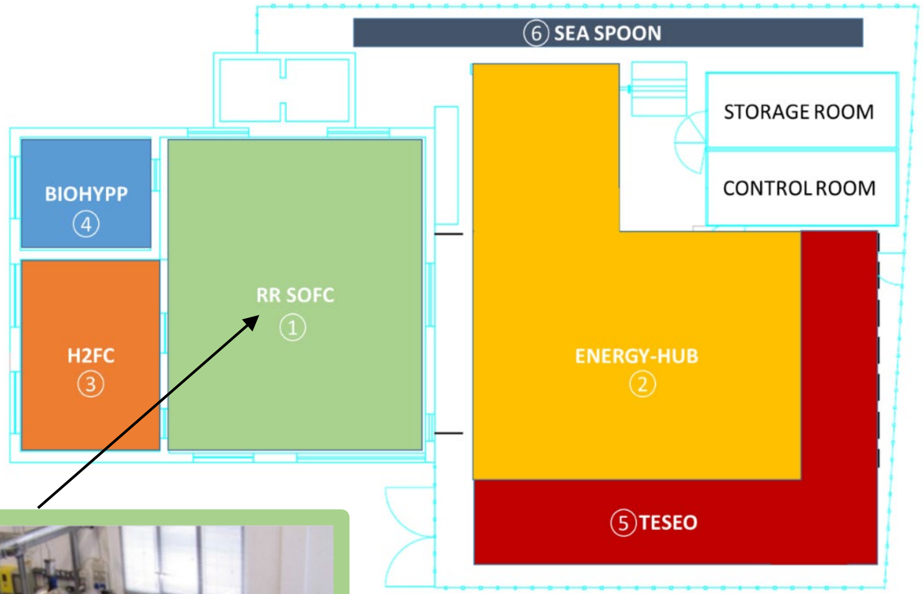
1 – Ferrari M.L., Traverso A., Massardo A.F., 2016, "Smart polygeneration grids: experimental performance curves of different prime movers", Applied Energy, vol. 162, pp 622-630

- This work is carried out at IES Lab of TPG in Savona
- The laboratory hosts different installation for studies on advanced energy systems
    1. 450kW(em) SOFC/Gas Turbine Hybrid System Emulator
    2. A smart grid emulator, including a microgas turbine, internal combustion engine, thermal storages, solar panels
    3. A laboratory on hydrogen storage system
    4. 30kW(em) SOFC/Turbocharger hybrid system
    5. 250kW Polymeric Fuel Cell Stack laboratory for marine application
    6. A wave flume facility for experimental analysis on wave energy converter
- The modified Turbec T100 was used to study the impact of the ambient temperature on the global performance
- A heat exchanger controls the compressor intake temperature
    - Three temperatures are investigated: 17°C, 22°C and 27°C





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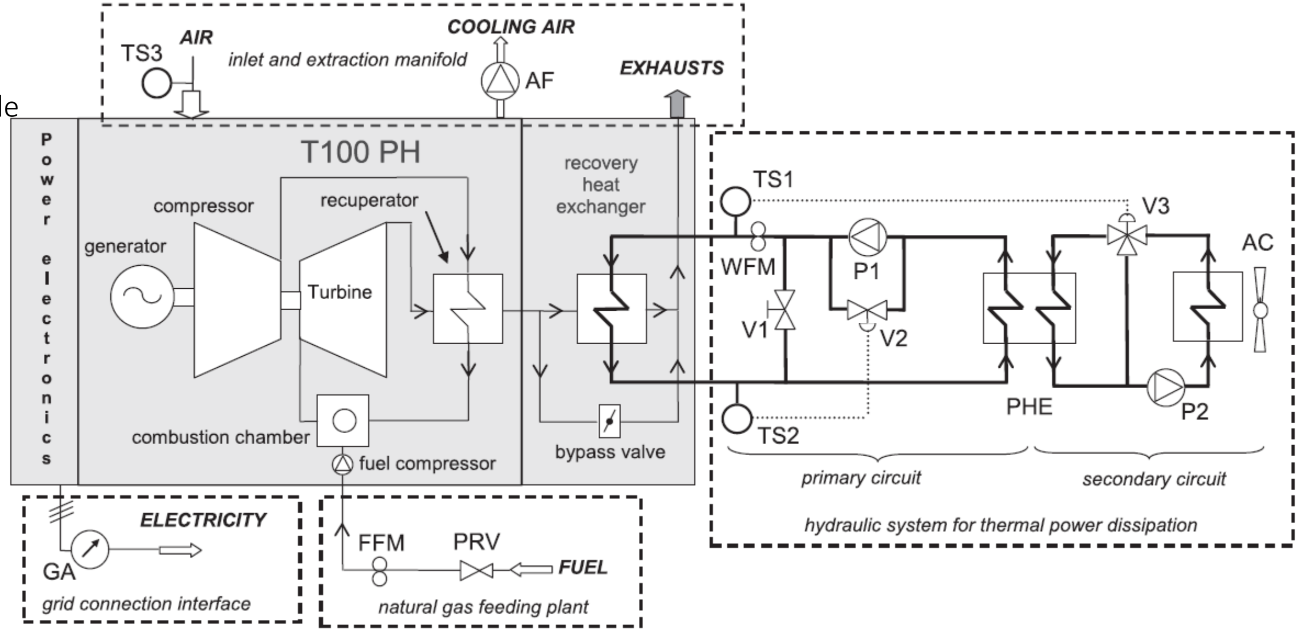
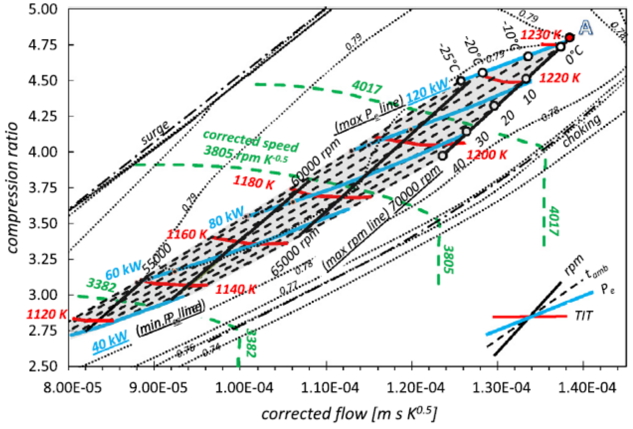
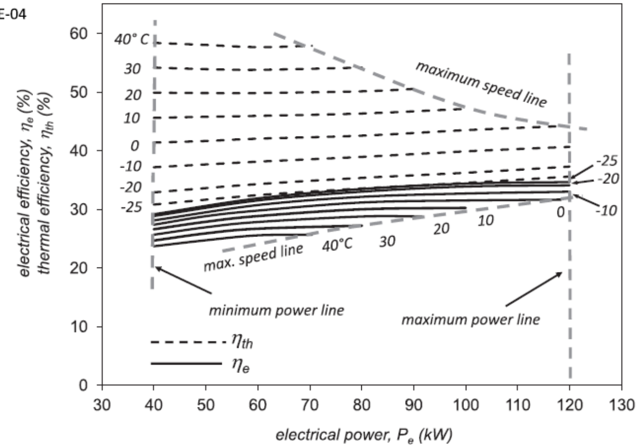
2 – Caresana F., Pelagalli L., Comodi G., Renzi M., 2014, “Microturbogas cogeneration systems for distributed generation: effects of ambient temperature on global performance and components”, Applied Energy, vol. 124, pp. 17-27

- In this work an in depth analysis is carried out at simulation level
- The model is aligned against experimental data based on their Turbec T100 test rig
- The impact of the ambient temperature is focused both on global performance and on single component operating point



AC	air cooler	TS1	temperature sensor for $T_{H_2O\_in}$
AF	air cooling fan	TS2	temperature sensor for $T_{H_2O\_out}$
FFM	fuel flow meter	TS3	air temperature sensor
GA	grid analyzer	V1	manual needle valve
P1	primary circuit pump	V2	pneumatic valve
P2	secondary circuit pump	V3	pneumatic mixing valve
PHE	plate heat exchanger	WFM	water flow meter
PRV	fuel pressure reduction valve		





Introduction

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- Both works are focused on Turbec T100 PH
  - The first one is based on experimental measurement from a modified engine working in controlled intake conditions
  - The second one consider a validated model and detailed simulation results for each conditions are analysed
- These two works propose different corrections for engine perfomance
- Variation obtained for each 1°C from 15°C in percentage is reported below

	Correction 1	Correction 2
Pel	-0.92%	-1.22%
Pth	+1.19%	-0.10%

- These values were considered background reference for the analysis carried out in the present work

Investigated Engine

- Present work investigates a standard AE T100 microgas turbine
- The engine has been tested within a room with controlled temperature
- The influence of the ambient temperature has been tested through different days of operation

NOMINAL DATA

- The AEN T100 is a CHP with a peak power 100kWe and 150 kWth
- It operates at 70000rpm with a TIT of 950°C
- Peak efficiency of 30%
- Fed by natural gas

Field Data Analysis

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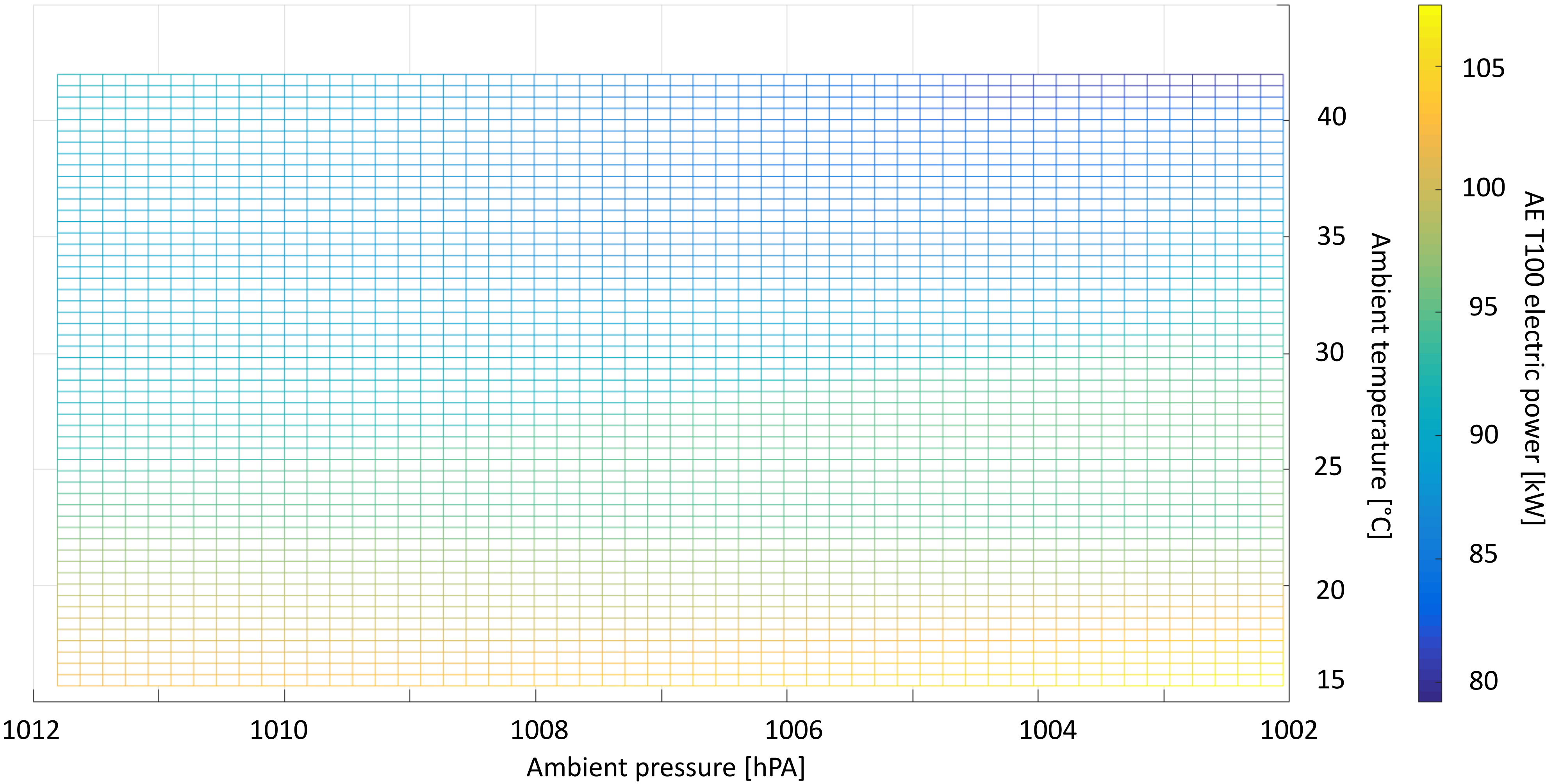
- Measured data were used to create a distribution surface of **electric power** in function of **ambient temperature** and **pressure**



Field Data Analysis

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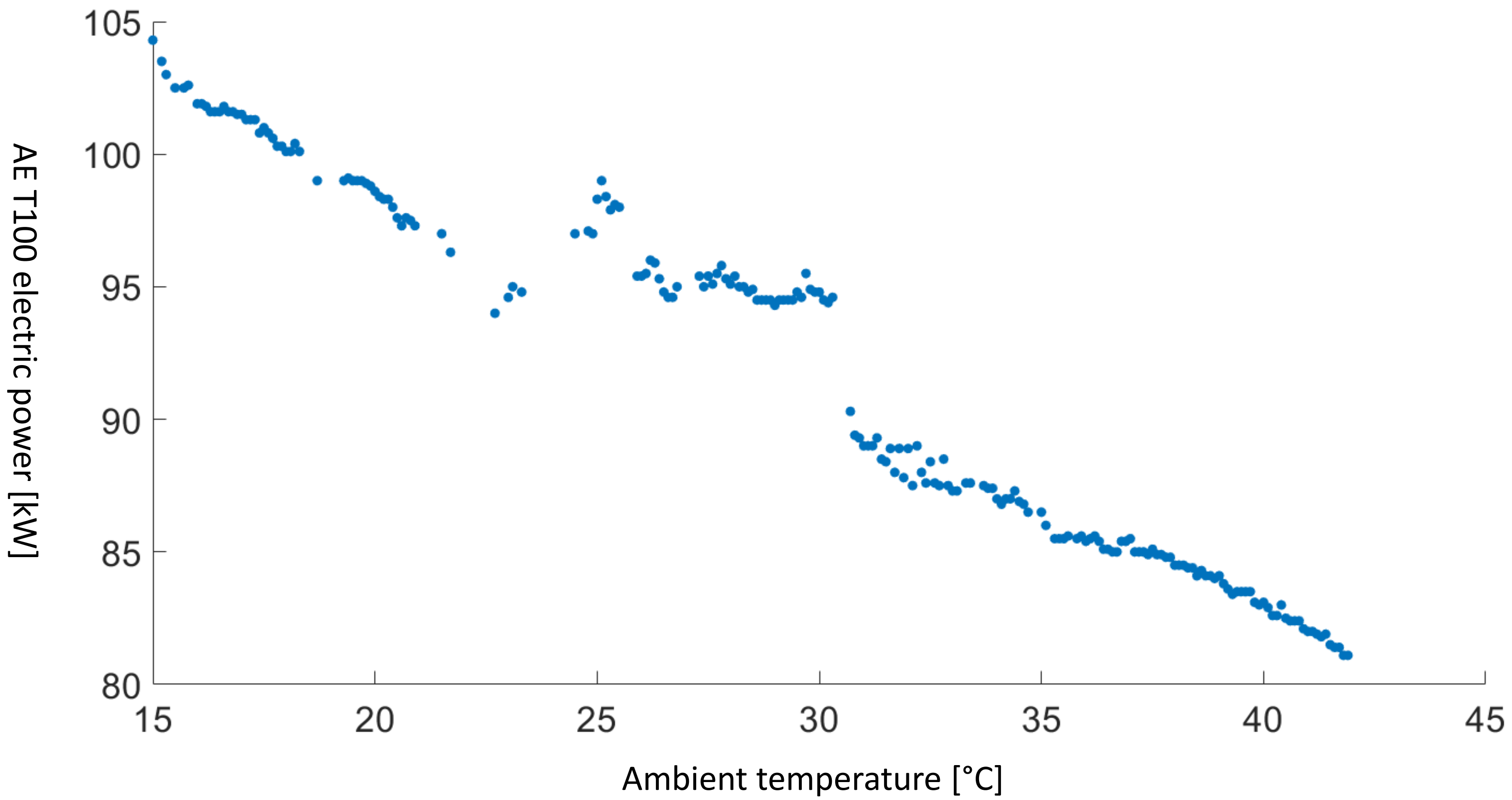
- Correcting all the performance for the actual pressure, the following diagram shows the impact of ambient temperature only
- In the data of ambient temperature there is a deviation in power (5 kW) which must be further investigated

(the variation is not linked to ambient pressure)



Comparison against reference

Avarage plant data at 100% load were compared against the correction curves proposed in the aforementioned works

1 – Ferrari M.L., Traverso A., Massardo A.F., 2016, “Smart polygeneration grids: experimental performance curves of different prime movers”, Applied Energy, vol. 162, pp 622-630

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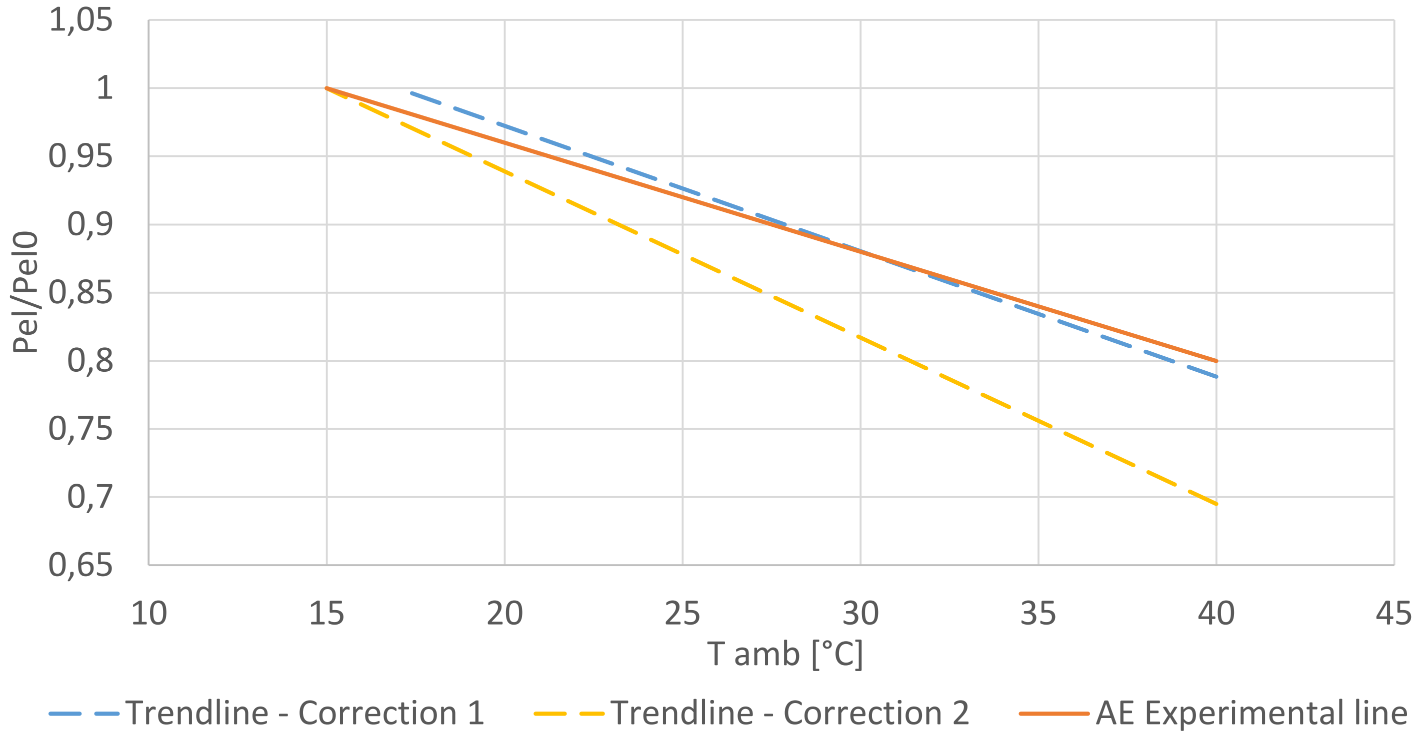
	Correction 1 – Modified T100	Correction 2 – Model
Pel	-0,92% per °C	-1,22% per °C



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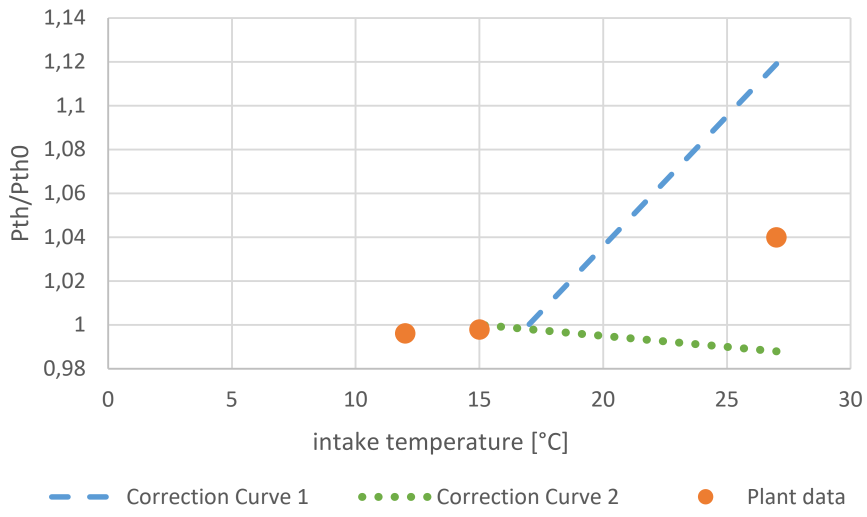
	Correction 1	Correction 2
Pth	+1.19%	-0.10%

- Thermal Power: Correction 1 overestimates the increase in thermal power
- Thermal Power: Correction 2 presents a negative trend, contradicted by field data



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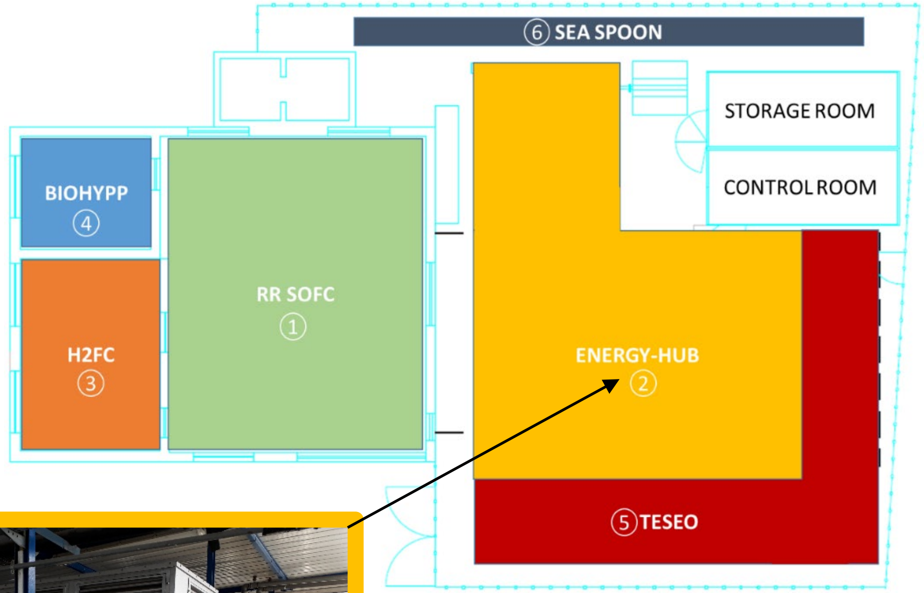
Comparison: mGT against ICE

- The investigated engine is a Turbec T100 from 2008 installed outdoor within the FP7 EU Project «Energy Hub»
- It is included in a framework emulating a polygenerative microgrid, together with an internal combustion engine, a biomass boiler, solar panels, thermal storage
- The whole package was used to test and validate different control logics for energy management within a smart grid environment
- The engine has been used also to produce energy for the University campus smart grid
- The engine underwent over years several startups and quick transients due to control robustness tests
- The engine run basically during autumn, winter, spring and barely during summer
- Currently is under maintenance and updated for the new PUMP-HEAT test-rig

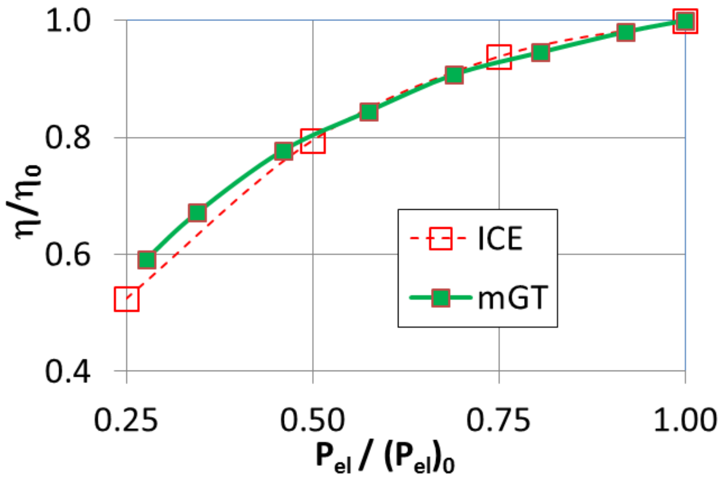
Nominal efficiency	30%
Nominal peak power	100kWe

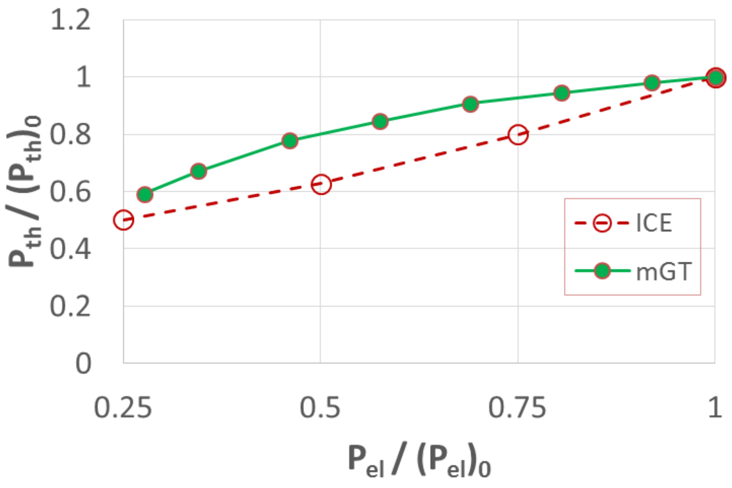


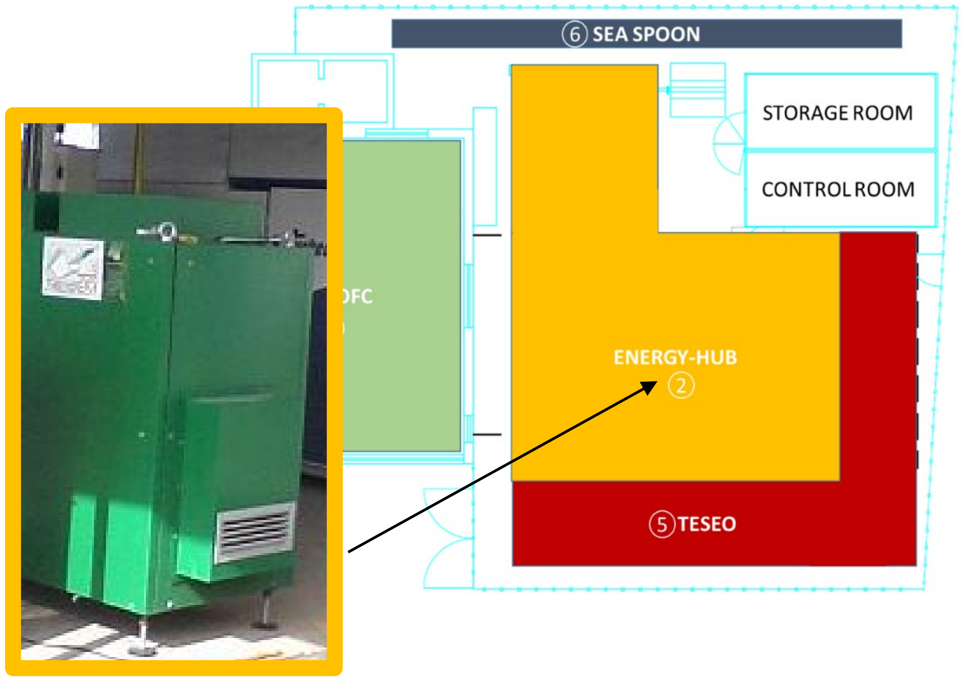
Comparison: mGT against ICE

Within the IES lab, the previous T100 machine has been compared against an ICE, at off-design conditions.

In this case, ambient temperature has not been varied.







The off-design behaviour of electrical efficiency shows a very similar behaviour for both engines.

The thermal power available remains higher for the mGT, at part load.

Tandem T20

(Cogenerative Internal Combustion Engine)

- Electrical Power 20 kW_e
- Thermal Power 47 kW_t (oil, water, exhausts)
- Non-condensing unit

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mGT fuel cell hybrid systems

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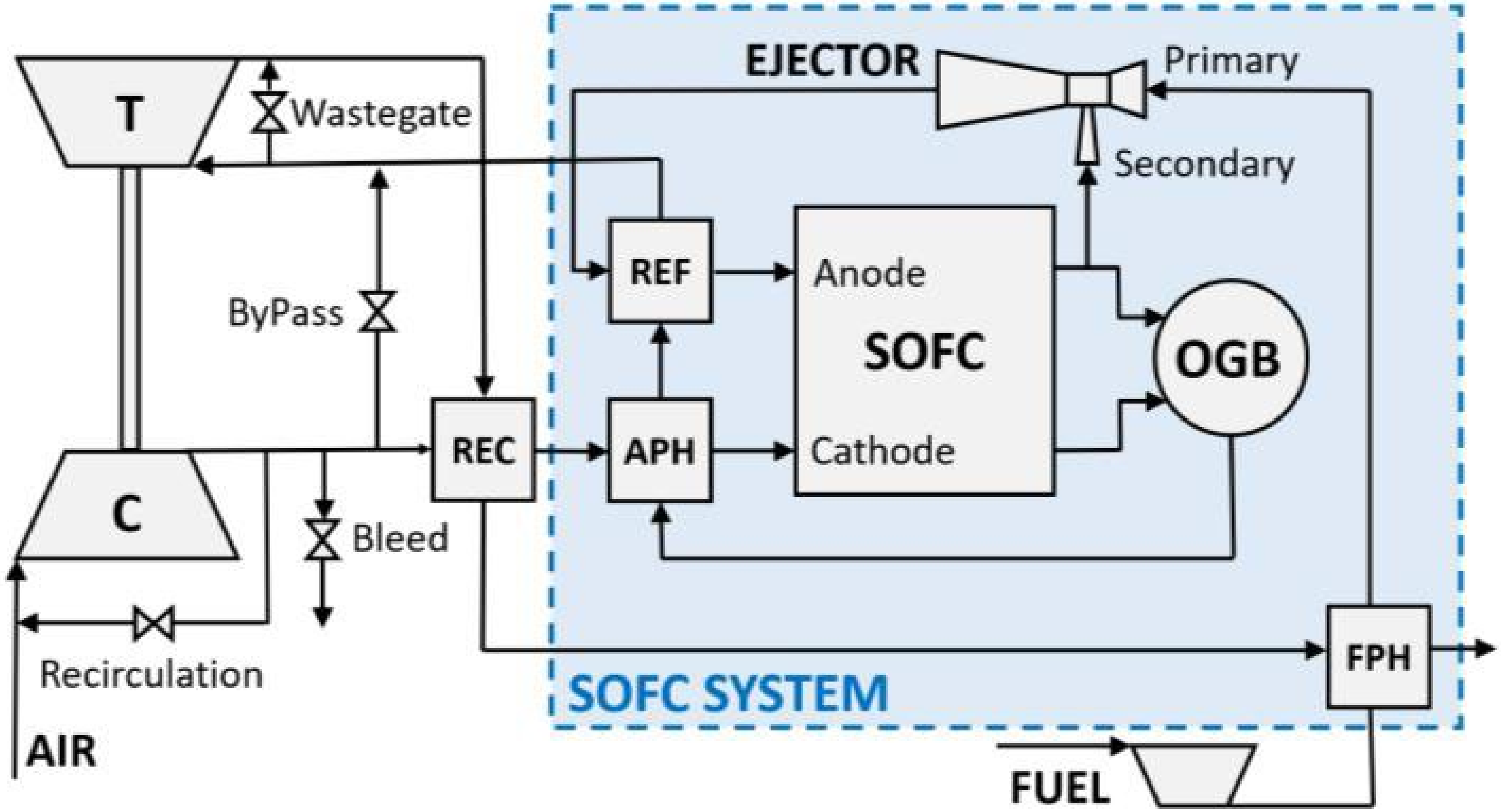
TPG is studying an innovative plant layout for small scale (30kWe) fuel cell gas turbine hybrid systems, integrating a turbocharger.

The Solid Oxide Fuel Cell (SOFC) stack is meant to be operated at high temperature (800°C) and at pressure (3-4bar).



mGT fuel cell hybrid systems

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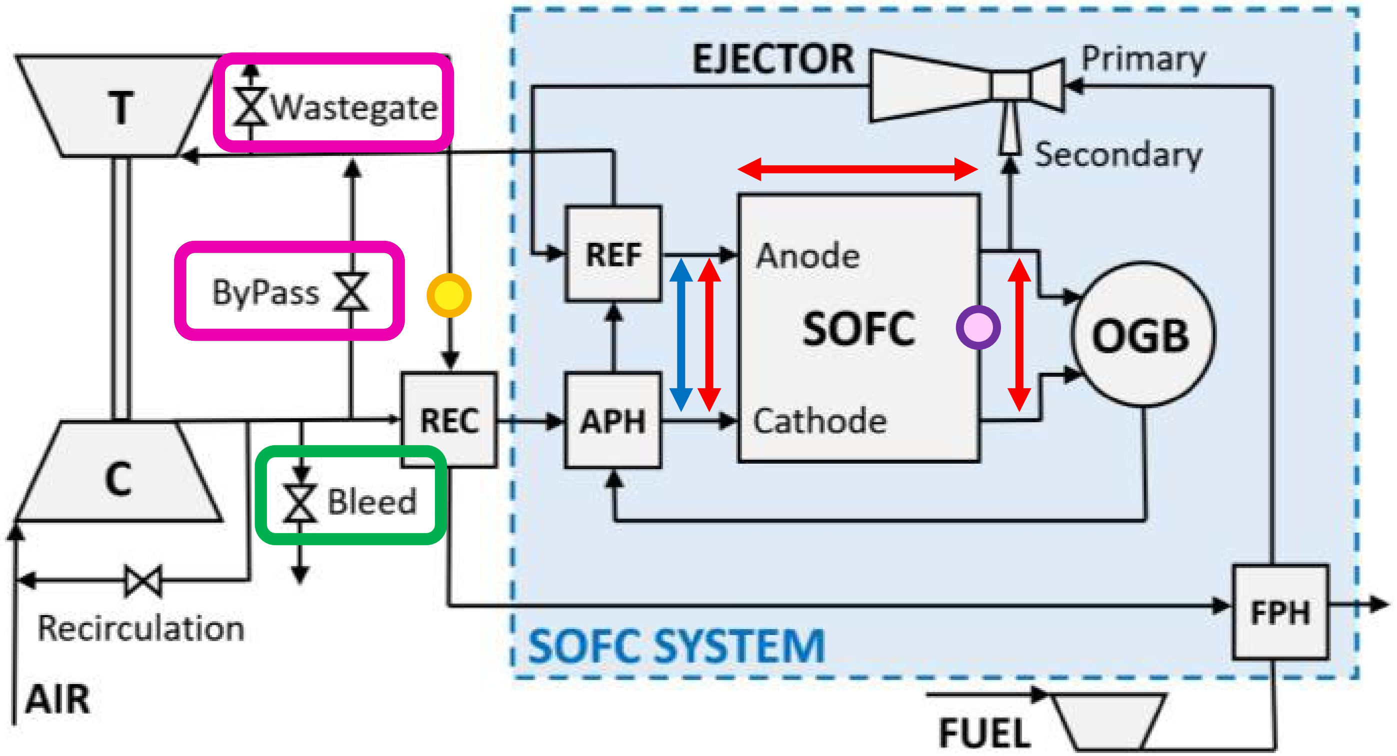
System operational constraints

- SOFC maximum T = 860°C
- SOFC T gradients ≤ 250°C
- SOFC p gradients ≤ 20 mbar
- REC inlet temperature (TOT) ≤ 650°C
- Surge margin > 1.1
- Rotational speed < 300 krpm

Control strategies

- Cold Bypass (+Bleed)
- Wastegate (+Cold Bypass)



mGT fuel cell hybrid systems

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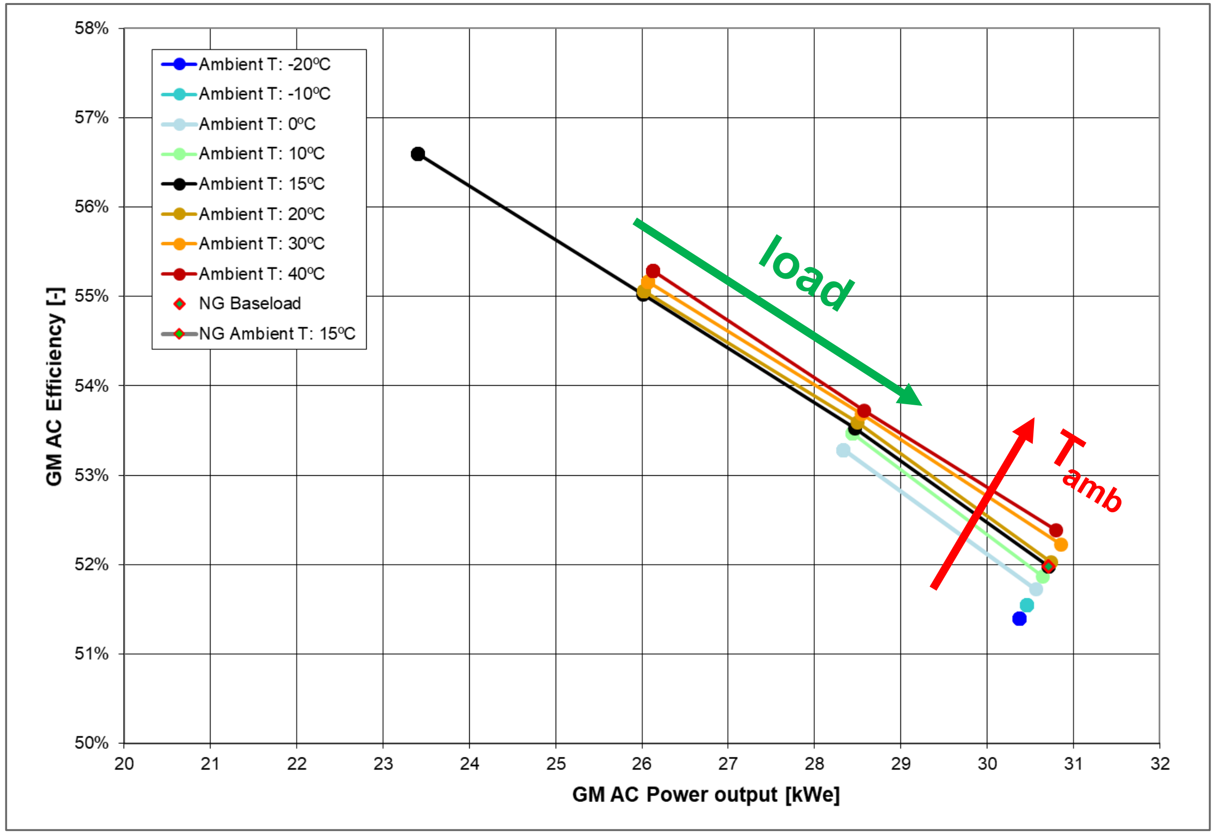
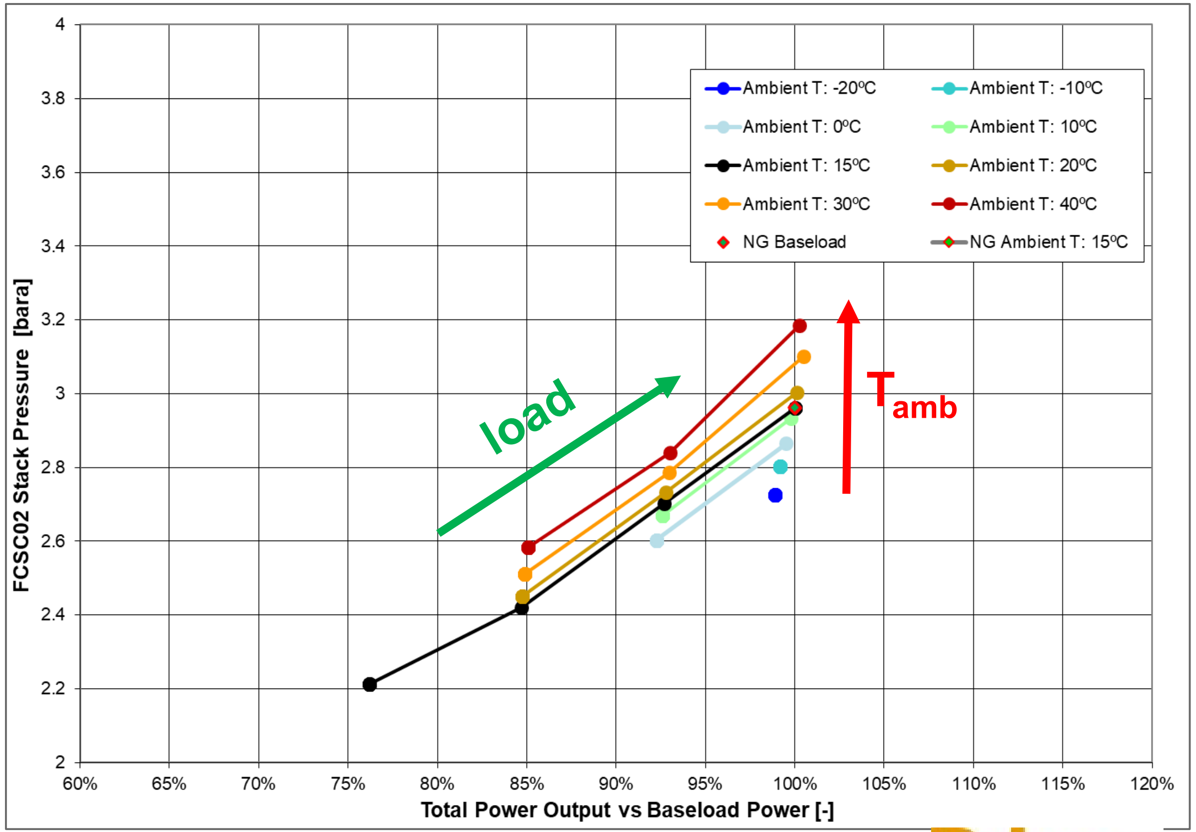
Off-design analysis at different load and ambient temperature conditions





Results show a clear positive impact of both part-load operation and hot ambient temperatures:

this is a complete change of paradigma from conventional thermal power plants!

Bio-HyPP

Conclusions

- An experimental analysis on field data acquired on a T100 microturbine has been compared against literature data
- The focus was placed on the ambient conditions impact on the mGT performance. Measurements tell:
  - The electrical power is reduced by 0.83 kW/°C per each 1°C growth from 15°C
  - The thermal power is increased by 0.5 kW/°C per each 1°C growth from 15°C
  - The efficiency is reduced by 0.31%/°C per each 1°C growth from 15°C
- A comparison of a mGT with an ICE of similar size showed the superior mGT thermal performance at off-design; electrical performance at part-load was comparable.
- A fuel cell micro gas turbine system shows a completely different behaviour:

  - at part load, efficiency is increased, thanks to the fuel cell internal characteristic

  - at higher ambient temperature, efficiency and power can be increased (if allowed by the hardware)

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Hints for thoughts: innovative micro wind

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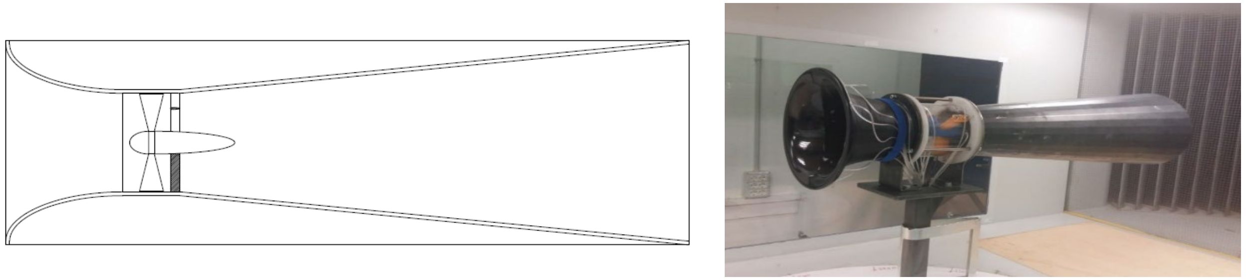
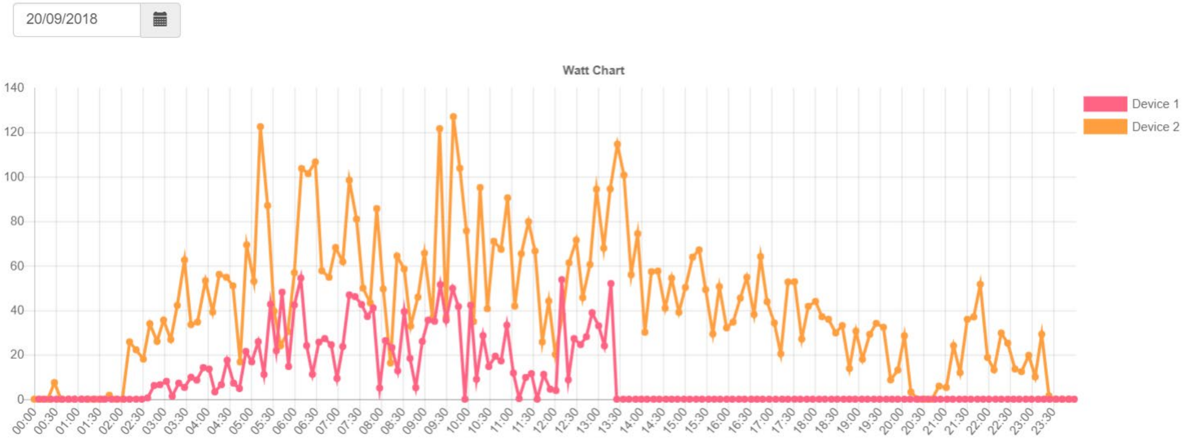
Ducted mini-wind technology can augment the rotor power by a factor up to 3, compared to the open space configuration.



Ducted mini-wind prototype for wind-tunnel testing at University of Genoa

kW scale demonstration, Genoa harbour



Ducted mini-wind can find application in

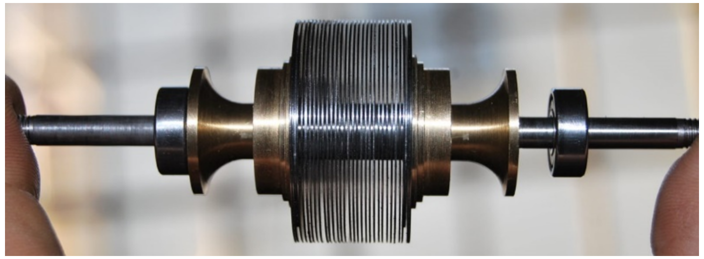
- integration in infrastructures
- integration in buildings

Hints for thoughts: Tesla expanders

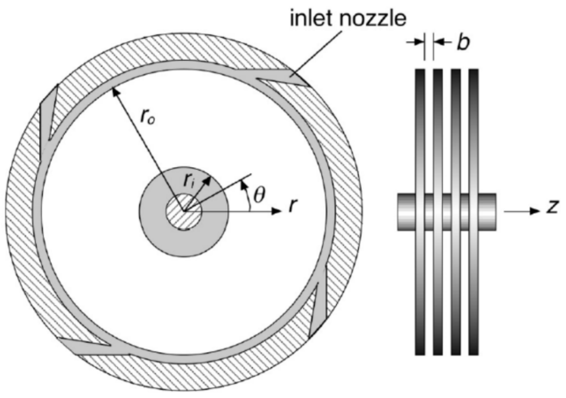
Boundary layer turbine (or bladeless) has been patented by N. Tesla in 1913.

Distinct features: friction is necessary to exchange work, simple manufacturing, limited impact of scale on performance, low noise.

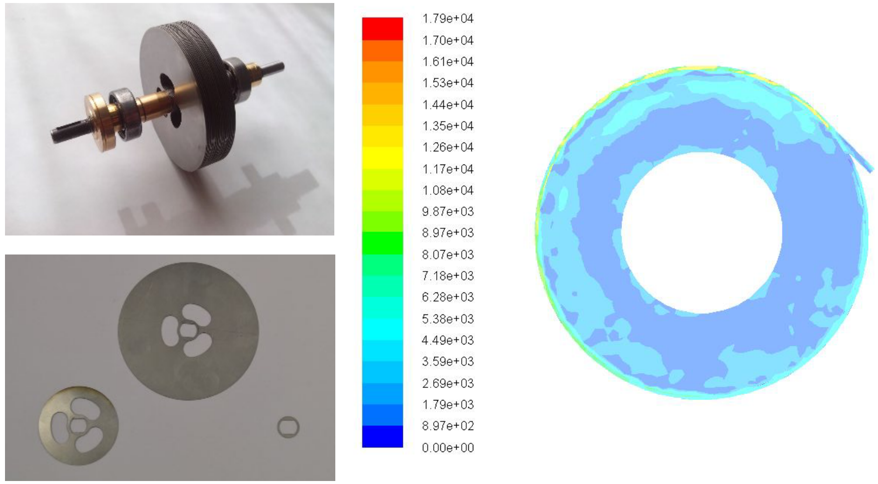
Disadvantages: low efficiency, rotor balancing.



100W scale Tesla rotor – University of Genoa



Tesla turbine schematic



Prototype rotor and turbulence in the rotor gap

Promising technology to be re-discovered for:

- Micro-harvesters (W scale)
- Dense fluids
- Bi-phase expansions

Acknowledgments

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http://www.pumpheat.eu/

This activity has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 641073

http://www.bio-hypp.eu/

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