Performance Untapped Modulation for Power and Heat via Energy Accumulation Technologies

PUMP-HEAT project

Flexible Combined Cycles for the future RES-based Energy Market

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Rina Consulting

Start Date: 1st September 2017
End Date: 31st August 2020

This Project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N. 764706

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PUMP-HEAT in a nutshell

THE NEED: Gas Turbine (GT) OEMs and energy utilities look for power flexibility especially for CHP Combined Cycles (CC), constrained by thermal demand, hence providing limited grid services.

THE IDEA: PUMP-HEAT proposes an innovative concept based on the coupling of CCs with a fast-cycling highly efficient **Heat Pump** (HP) equipped with **Thermal Energy Storage** (TES).

The integrated system features an **advanced control** concept for smart scheduling:

- the HP modulates power to cope with the CC reserve market constraints;
- the *high temperature heat* can be exploited in the district heating network (DHN);
- the *low temperature cooling* can be used for gas turbine inlet cooling.

The CC integration with a HP and a cold/hot TES brings to a reduction of the Minimum Environmental Load (MEL) and to an increase in power ramp rates, while enabling power augmentation at full load and increasing electrical grid resilience and flexibility.

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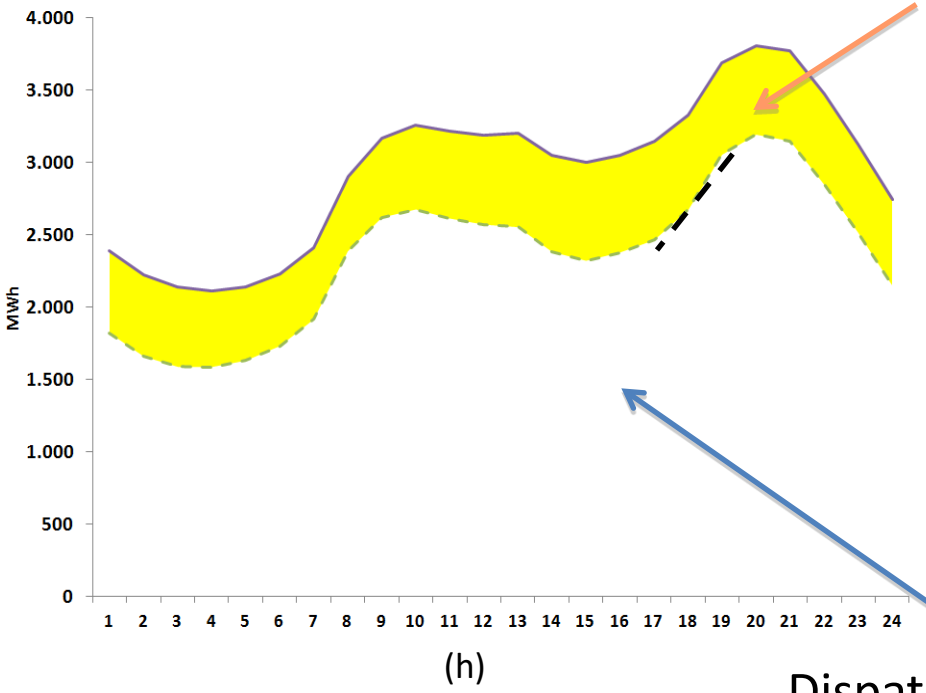
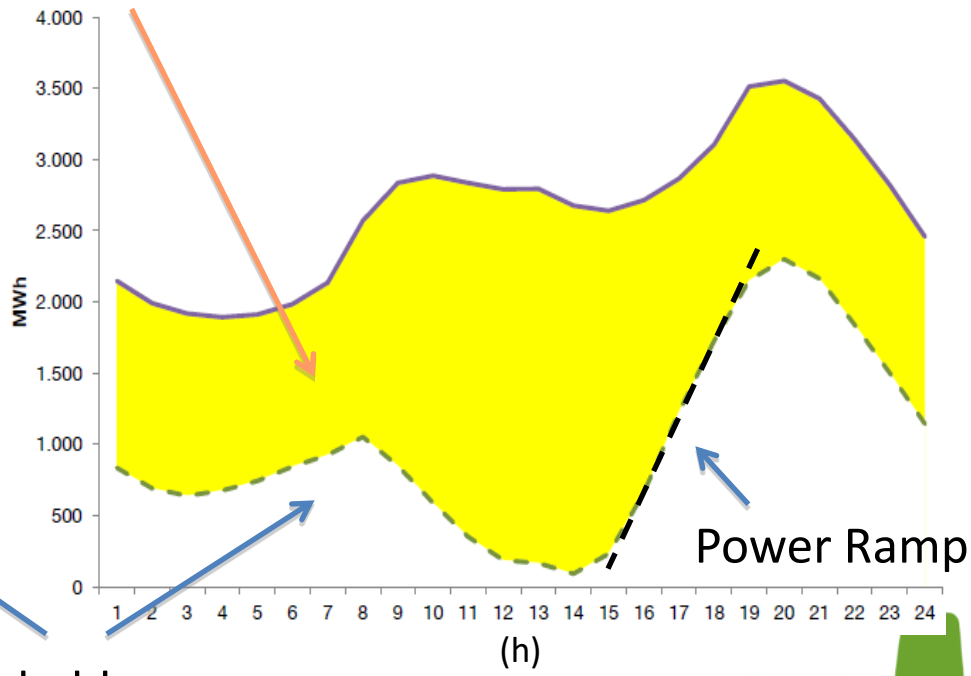
Why CC flexibility?

March 2010* – working day

March 2017* – working day

PV and Wind





Power Ramp

Dispatchable power

*Italian case

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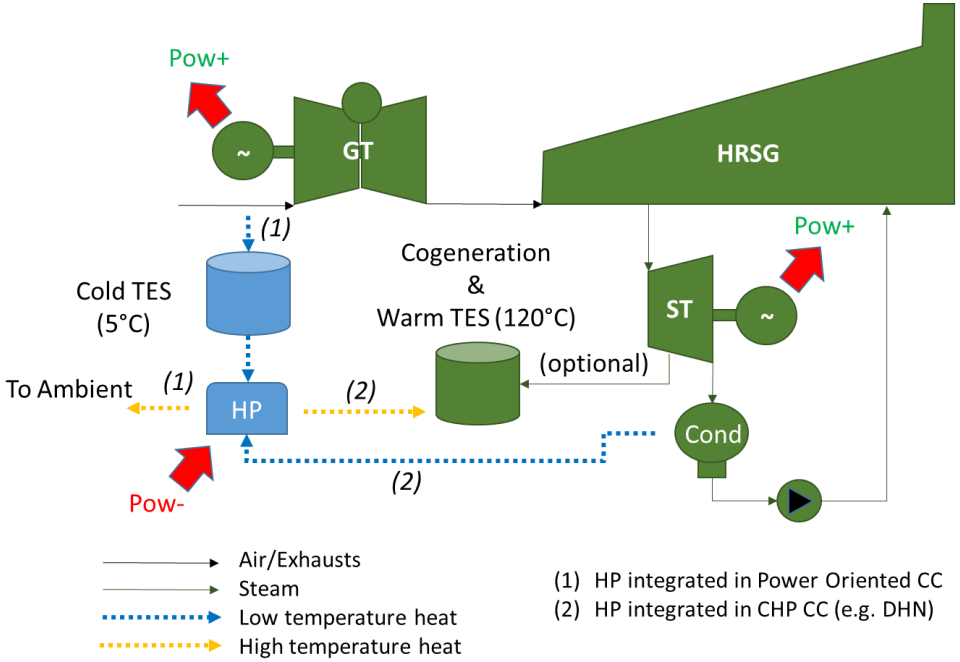
PUMP-HEAT concept overview

- Heat Pump (HP) as a *smart electrical load*
- HP may allow CC to sell grid services also when the CC is off
- HP will impact on the GT inlet air, reducing P_min and augmenting P_max as required
- HP can produce useful heat for DHN, displacing auxiliary boilers
- HP will also increase the CC average annual efficiency



1 Validation site in Savona (Italy) for the PO layout
1 Demosite in Turin (Italy) for the CHP layout

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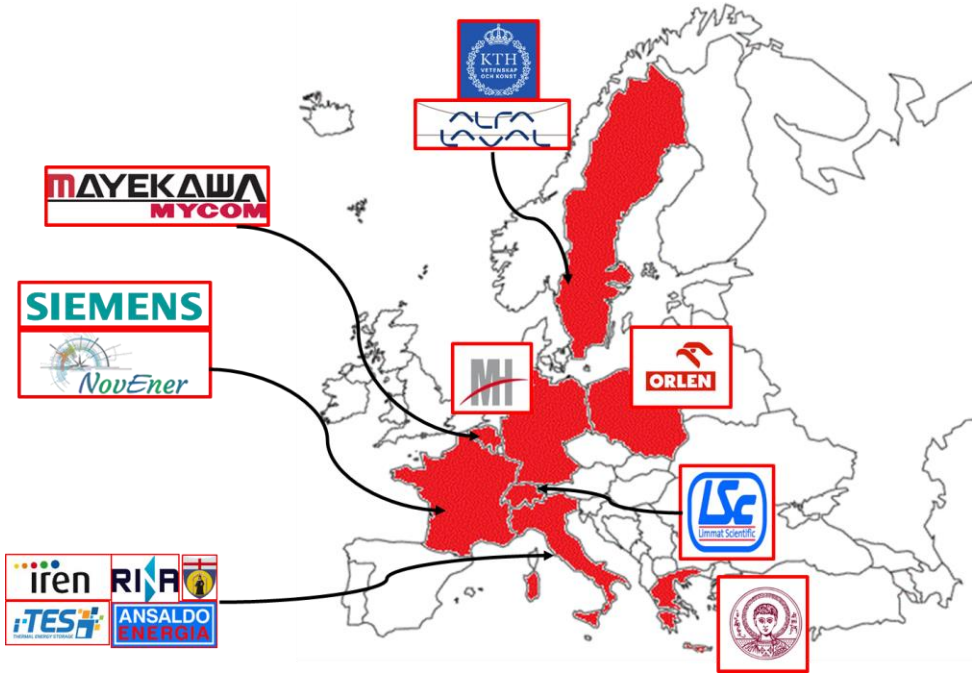
PUMP-HEAT Consortium



PUMP-HEAT

an Industry-driven Consortium

This guarantees:

- Industrial and Market interest to project outcomes
- Involvment of wide range of stakeholders
- Strong commitment to PHCC realization
- A common «project business» to be pursued made by «different actors' business»
- Ability to overcome contingencies

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A *demonstration-to-market approach*, as excellence for Research Innovation Actions

Key Exploitable Results	TRL
HOT TES	8
COLD TES	4
Steam HP	4
Hot Water HP	4
INNOVATIVE TURBOEXPANDER	4
CONTROLLER	4
HEAT EXCHANGER	5
PHCC LAYOUT	3

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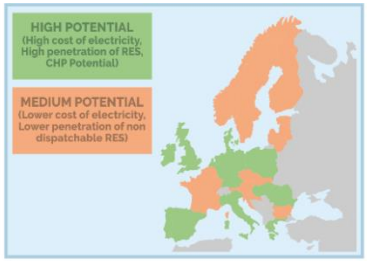
HEAT EXCHANGER	8
PHCC LAYOUT	8



MAIN APPLICATIONS:

Combined Cycle (CHP or Power Only)

MARKET DRIVERS:

- De-Moothballing of Combined Cycle
- Increasing of RES penetration
- Need for an Increased Back-Up Capacity of Flexible Power Plants
- Increase of CHP penetration for process industries

ADDITIONAL MARKETS:

Integrated Industrial CHP Plants

Large Size DHN CHP Plants

PROJECT STARTS 2017 — 2019 — 2020 (TRL 6) — 2021 (TRL 8) — 2023 (TRL 9)

Project Starts

Project Drivers

- Flexibilization of Natural Gas Based Power Plants to increase their role in electrical market
- Fast-Response Back-up Capacity for fluctuating RES
- Increase the efficiency and the performances at minimum and part load of the plants
- Demonstrate a "Thermal Equivalent" Electrical Storage
- Use of HP as Smart Load for the Electrical market and increase their efficiency

Intermediate Achievements

Demonstration at Moncalieri IREN CHP Power Plant

Standards and norms definition	• Heat exchangers and containers fro PCM storages and the coupling with HPs need to be standardized in terms of geometry and size according to the stored energy capacity • Definition of rules for the installation of the PUMP-HEAT upgrade • Overcoming normative barriers for what concerns the interaction with the electrical grid • Standardization of control systems protocol
Manufacturing	• Upscale the production capacity of PCM and Hot water/steam HP with consequent reduction of the costs due to economy of scale • Development of high temperature and steam hot pumps • Full integration of the turboexpander in commercial heat pumps
Further demonstrations	• Demonstration of the concept at full scale • Application in other countries (environmental and electrical market contexts)
Marketing	• Start to promote the coupling of heat pumps with CC and GT plants • Selection of the first entry markets • Assessment of the final business model for the commercial exploitation of the concept • Advertising and awareness campaigns for increasing the promotion of the PHCC layout

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A *demonstration-to-market approach*, as excellence for Research Innovation Actions

Demonstration in IREN Moncalieri CHP CC (+DHN)

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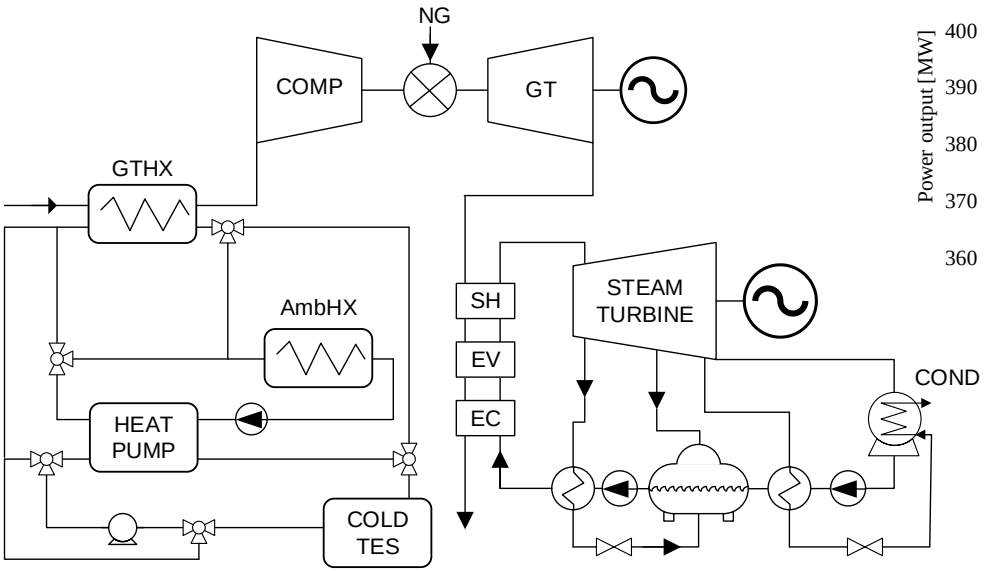
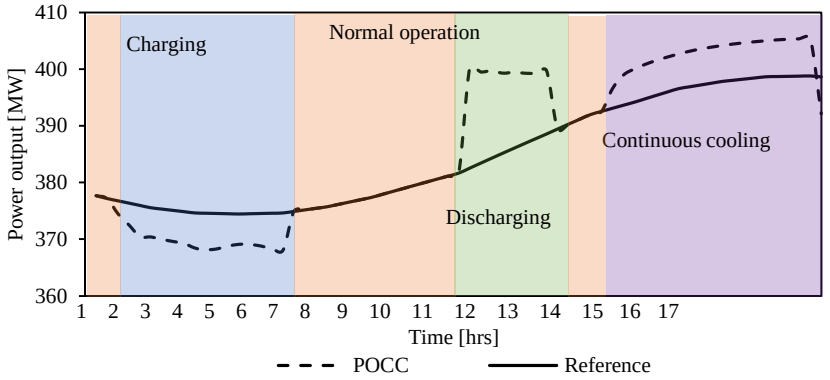
Key Exploitable Results 1/3

KER 1 - **Innovative plant layout for combined cycle** plant integrating a fast cycle heat pump and thermal energy storage to increase part-load efficiency, reduce the minimum environmental load and increase power ramp rates, enhancing the flexibility

Power Oriented Combined Cycle (POCC)





- Flexibility in max electrical power and ramps
- Increased production in peak hours
- Competitive in markets with large price fluctuations and pronounced periods of peak power (when compared to mean price)

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Thermo-economic results for PO layout

PO PHCC was detailed modeled to assess flex enhancement:

- Starting from 35°C an Increase of the Pmax of +14% was assessed using the **cold TES** , up to +12% adopting direct cooling with **HP**, with a slight negative effect over the efficiency (-0.56 pt%)
- Reduction of the **Minimum Environmental Load** (Pmin -17%, with a reduction of just 1.5 pt% of efficiency. Overall reduction of fuel consumption and CO_2 emission during turn down period.
- **Enhancement of annual average efficiency** by inlet heating of ca 2% delivering the same amount of Electricity (estimated on year of Turbigo power plant operating data)
- Such technical performance will be used to increase CC profitability:
  - in the Day Ahead Market
  - in the Ancillary Service Market

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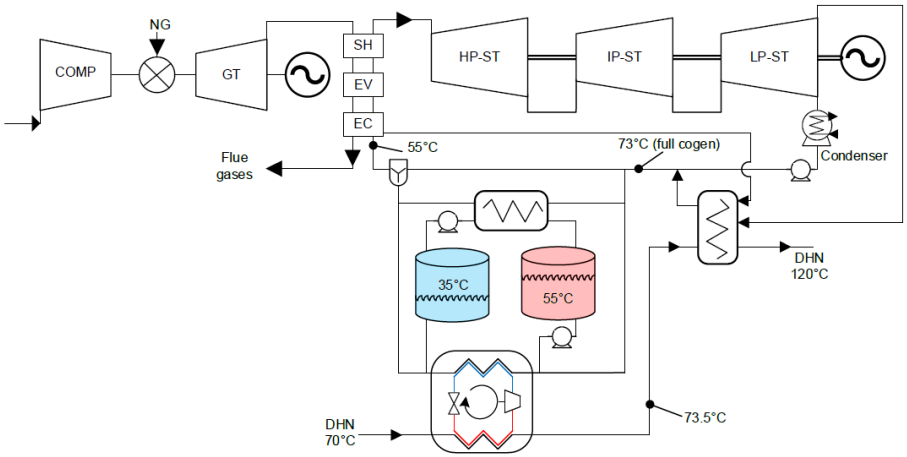
Thermo-economic results for CHP layout

CHP PHCC was detailed modeled to assess economic sustainability:

- The main advantage is related to operate the **HP as a smart load**
- The integration of CC and HP **increases the global efficiency up to 1 pt%**
- Despite the higher capital costs, the heat pump integrated in series with the CC presented a lower payback period thanks to the higher COP.
- Actual market conditions are still not completely favorable to this kind of innovative plant layout leading to interesting economic results (**IRR = 10%**), exploiting low electricity prices substituting Combined Cycle and Heat Only Boiler production.
- The use of a. low temperature TES to increase the Peak capacity of the system, is under investigation



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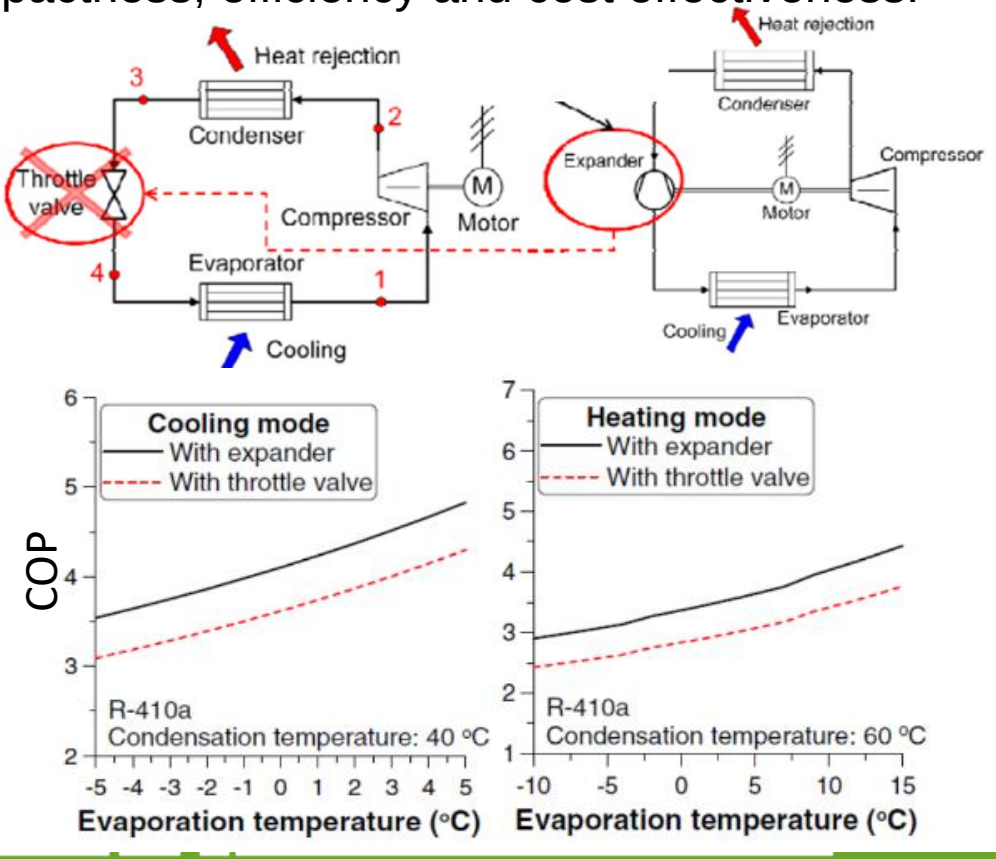
Key Exploitable Results 2/3

KER 2 - **Innovative two-phase turboexpander for high efficient Heat Pumps** will be developed from laboratory to demonstration. This turboexpander will be substituting the HP lamination valve, promising compactness, efficiency and cost effectiveness.

An expander is required to replace the HP lamination valve, producing power. The theoretical potential performance improvement of COP should be up to 15 – 20%, depending on various cycle characteristics.



Challenges:

- two-phase flow expansion
- vibrations
- blade erosion

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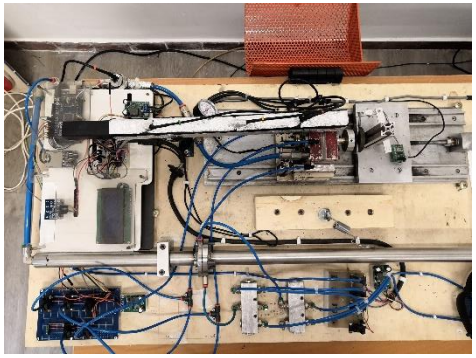
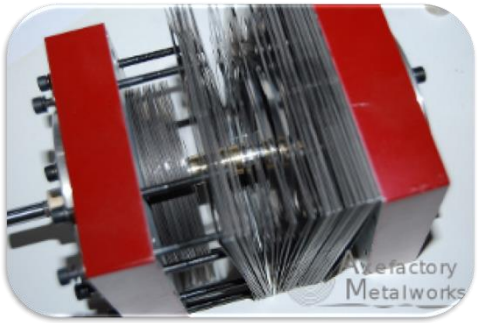
Turbo Expander – Experimental Set Up

Innovative small scale turbo-expander for high efficient Heat Pumps will be developed from laboratory to demonstration. One of the potential type of expander, Tesla expander*, has been investigated.

- Tesla expander consists of thin smooth disks mounted parallelly on the shaft with gap between disks. Fluid enters tangentially, makes spiral path and leaves axially, imparting energy to the disks
- Preliminary experimental performance investigation of Tesla type turbo-expander of 100 W rated power, has been performed with air as working fluid at TPG, UNIGE
- Significant geometric parameters affecting performance of expander has been analyzed experimentally and numerically
- Loss characterization is carried out experimentally and numerically



Experimental Set up



Expander prototype

*Patent Application no. PCT/EP2017/084660 (WO2018/127445 A1) "Reverse Cycle Machine Provided with a Turbine", Traverso A, Silvestri P, et al.

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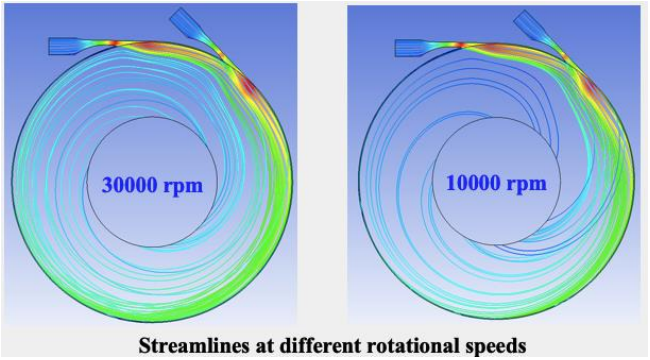
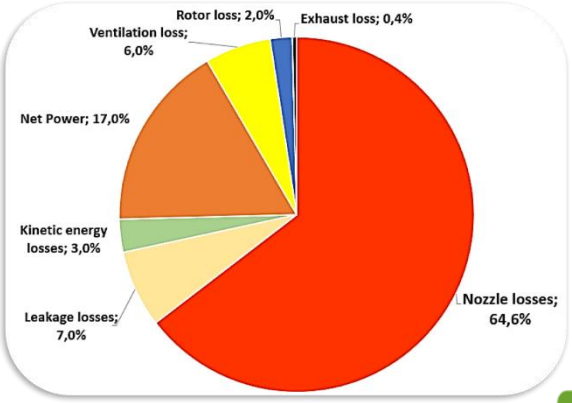
Turbo Expander – Results and Future Developments

Results

- ✓ Experiments show max power of about 150W @40000 rpm, well exceeding the design power.
- ✓ CFD results shows max pressure drop occurs inside nozzle, making it impulse type turbine
- ✓ Analysis of losses shows that major losses occurs inside nozzle and leakage losses
- ✓ Parametric study shows that geometric parameters have significant effect on performance and should be selected carefully
- ✓ Tesla turbines are promising due to its simple construction and flexibility of operation with variety of fluids



Streamlines at different rotational speeds



Loss characterization

Future Developments

- 3 kW Tesla expander prototype coupled with PHASE generator for full size demonstration
- Investigation of challenges : two phase fluid, vibration and performance improvement

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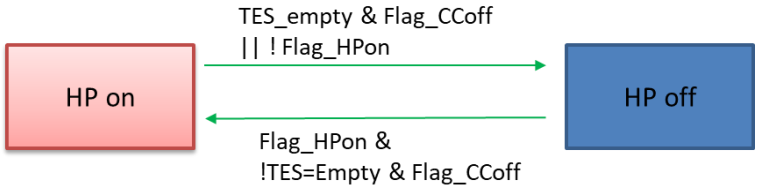
Key Exploitable Results 3/3

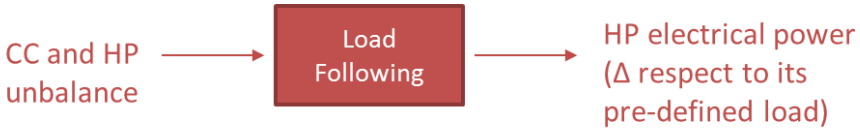
KER 3 - **Multi-level Model Predictive Control** to enhance the predictive capability (24-hours) and real-time capability, optimizing performance and safety of a PH combined cycle including Heat Pumps and Thermal Energy Storage.

High level: clock @24h
Role: Take decisions



Intermediate level: clock @15min
Role: Manage states and transitions

Low level: clock @1s
Role: Load following



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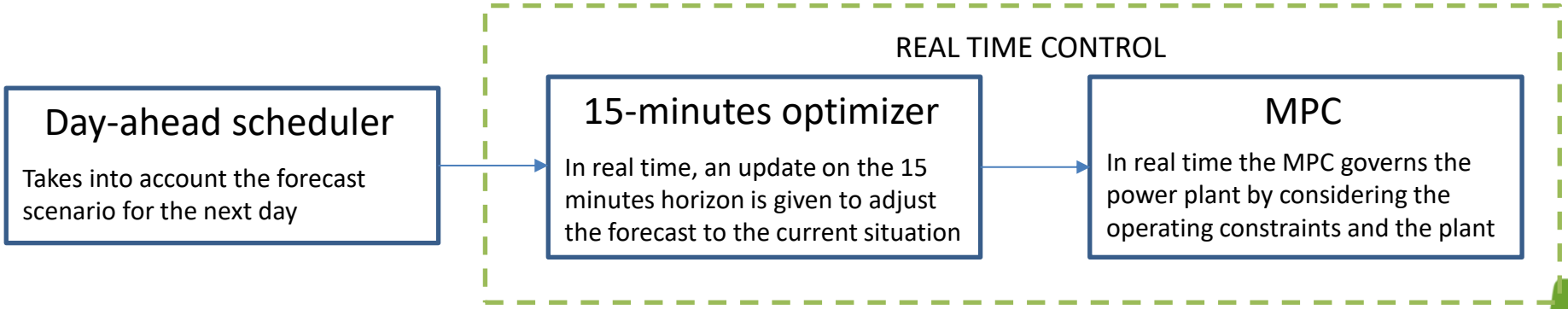
PUMP HEAT – Control Algorithm

A **predictive control algorithm** for real-time supervision and management of the PHCC will be **investigated, prototyped, virtually tested at simulation level, verified in hardware-in-the-loop, and implemented in the demosite**. The objective will be to track the best thermo-economic performance through real-time multi-objective optimization considering market requirements, secondary regulation market unbalance, plant efficiency, thermal storage levels and operational constraints.



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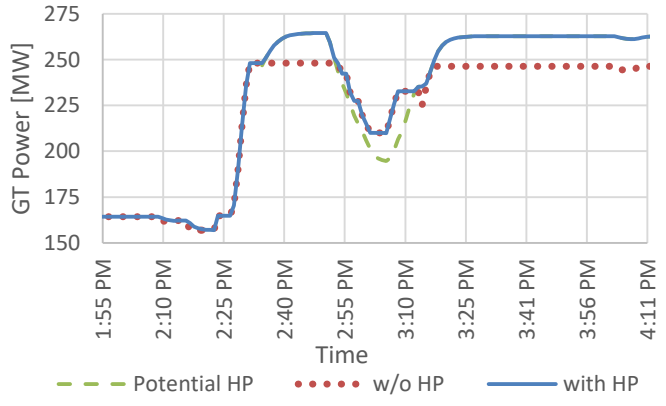
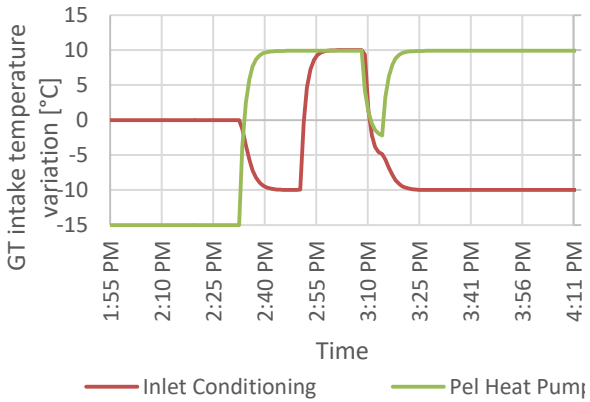
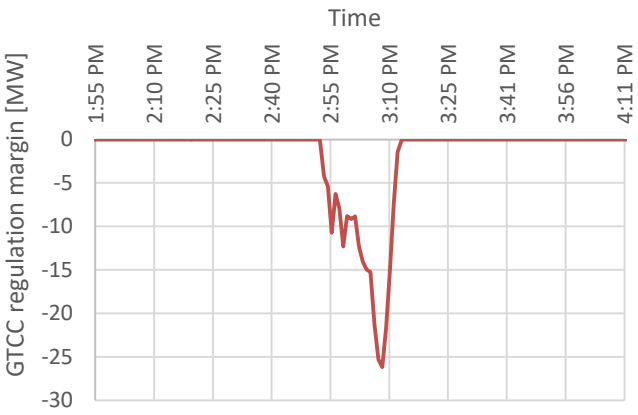
Control development results

- Control development ongoing
- Software in the loop arrangement in progress
  - Correlation between HP and GTCC included on the basis of WP1 results







PO case study

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Dissemination

Close collaboration with

European Turbine Network

ETN AT WORK

INTERVIEW:

Alberto Traverso, PUMP-HEAT project coordinator

The EU funded PUMP-HEAT project (Performance Untapped Modulation for Power and Heat via Energy Accumulation Technologies) was kicked off in September. The objective of the project is to increase the flexibility of the Combined Cycle power plants and the operation of gas turbines. We interviewed the project coordinator Alberto Traverso, Professor of Energy Systems at University of Genoa, who leads the consortium

and plans are also expected to cover the doubling of gas fired generation expected within 2035. According to all these issues, the foreseen NG based power capacity in 2030 will be around 230 GW starting from the current capacity of 191 GW.

What are the main objectives of the project?

To un-tap the unexploited reserve of flexibility in cogenerative CCs, and to further enhance turn-down ratio and power ramp capabilities of power oriented CCs, PUMP-HEAT project proposes the demonstration of an innovative concept based on the coupling of a fast-cycling highly efficient heat pump (HP) with CCs. The integrated system features thermal storage and advanced control concept for smart scheduling.

IGTC'18 conference by ETN, Brussels, Oct 2018

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http://www.tpg.unige.it/TPG/SUPEHR19/

SUPEHR conference

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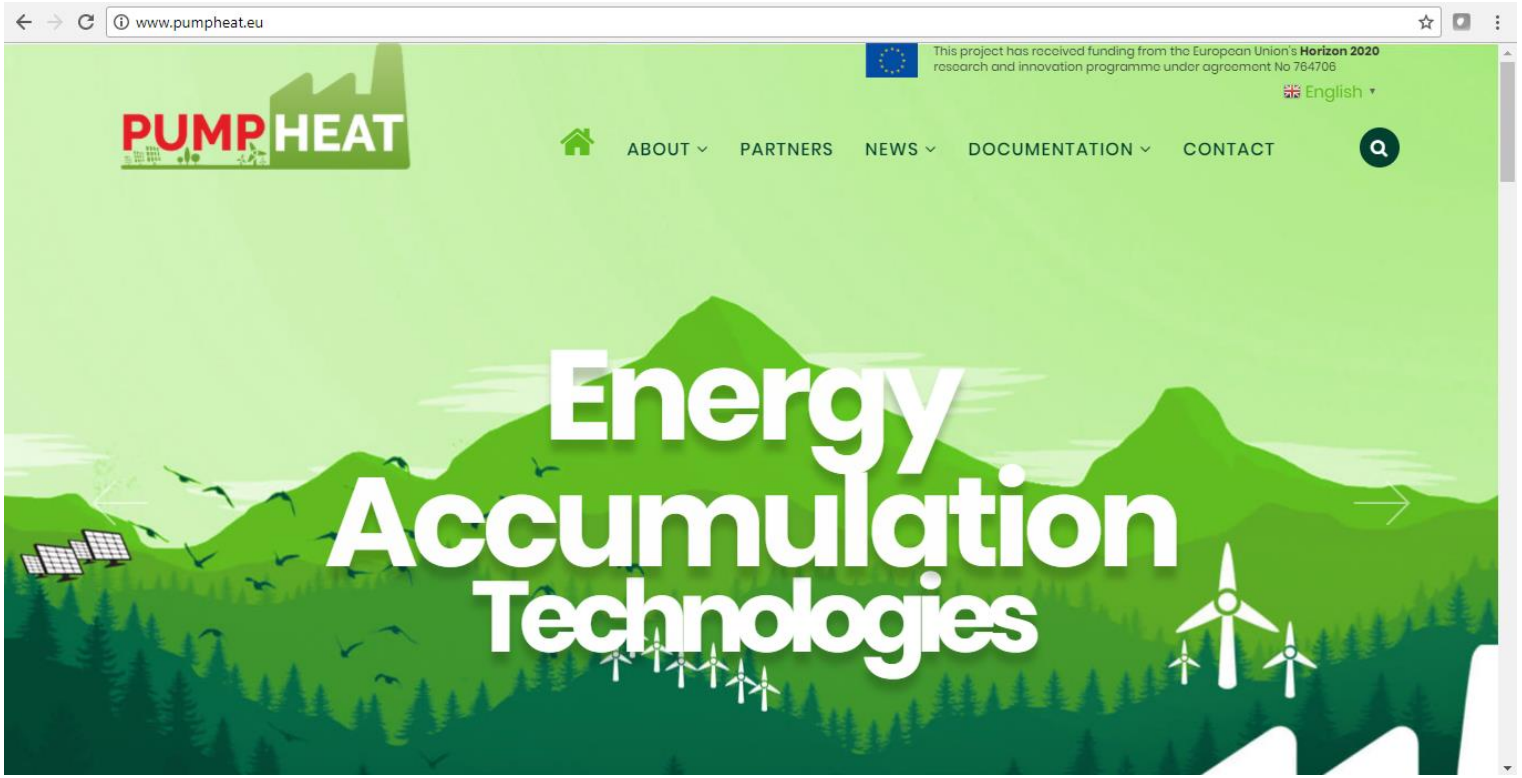

www.pumpheat.eu

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THANKS FOR YOUR TIME

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