Modelling and optimization of a flexible PEMFC power plant for grid balancing purposes

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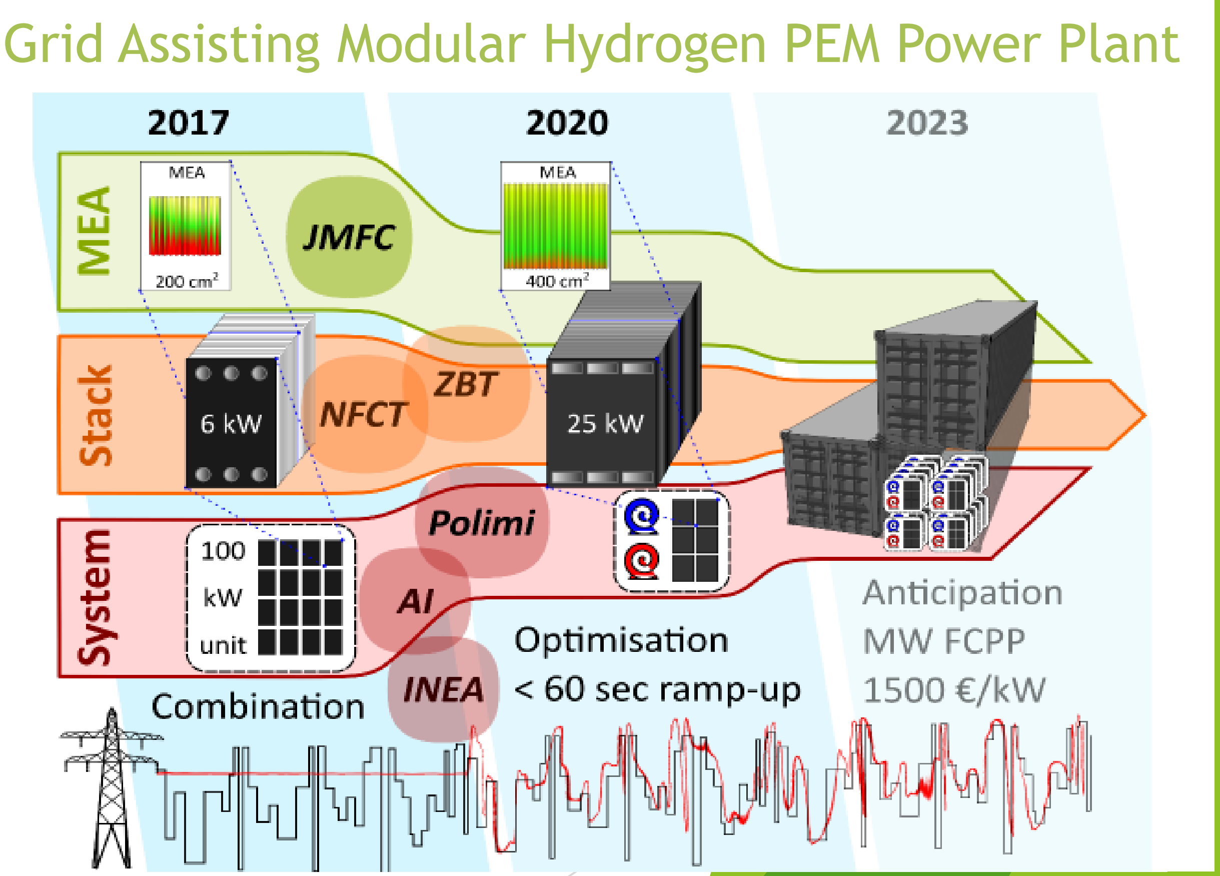
GRASSHOPPER project

- This work is developed within the EU Project GRASSHOPPER, aiming at analysing how distributed and fast-ramping Fuel Cell Power Plants (FCPP) can be used to provide ancillary services and help balancing the grid.
- The project will setup and demonstrate a 100 kW_{el} PEM FCPP unit:
  - cost-effective
  - flexible in power output
  - scalable to MW-size
  - for grid support with a Demand Side Management program



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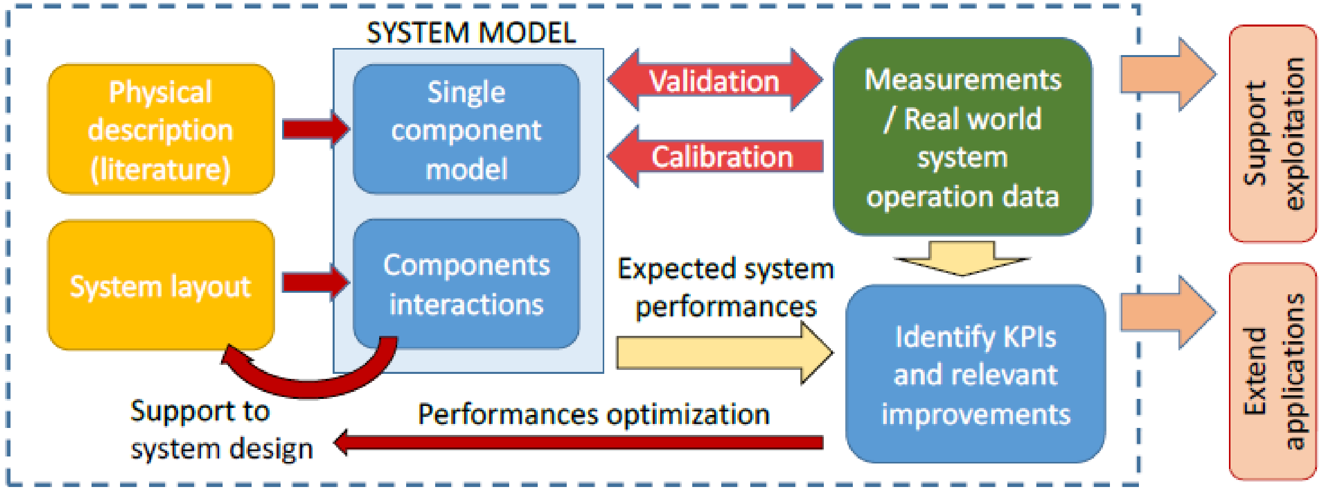
Modelling activities

- Two different configurations for the GRASSHOPPER pilot plant are simulated to:
  - support the decisional process for defining the plant configuration;
  - optimizing the plant expected operating conditions and evaluate its performance;
  - to investigate the behaviour of the system in off-design conditions, influencing the definition of an optimized plant control strategy.
- A stationary model of the FCPP in Aspen Plus®:
  - PEMFC customized model
  - main balance of plant components



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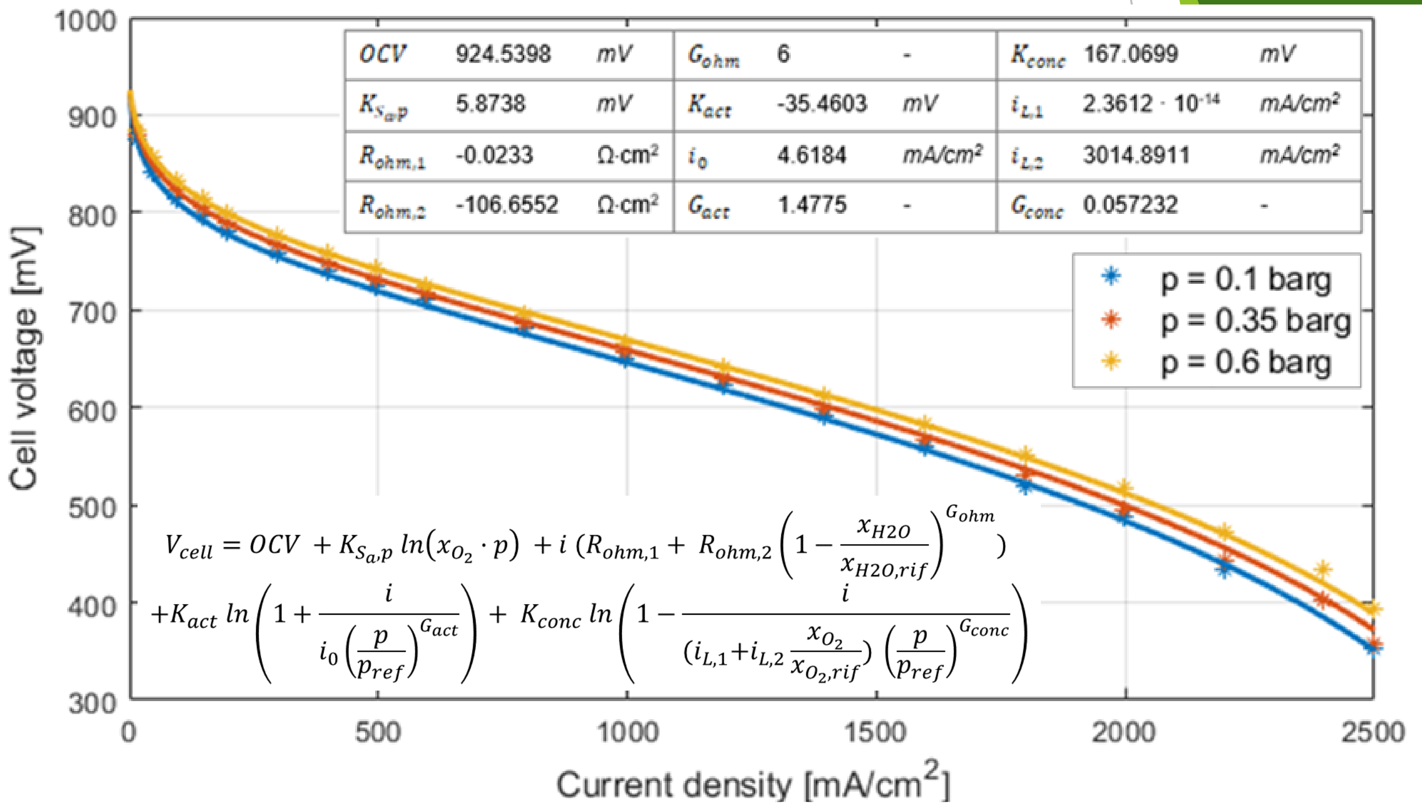
Modelling approach: PEMFC model

- Lumped-volume approach.
- Semi-empirical equation of the cell polarization curve, including the effects of:
  - Stack backpressure
  - Air ratio to stoichiometry
  - Air relative humidity
- Regressions are made for a single cell:
  - relative errors always below 8%
  - Relative errors below 3% below 1.5 A/cm^2



Cells polarisation curves obtained from CFD simulations at ZBT

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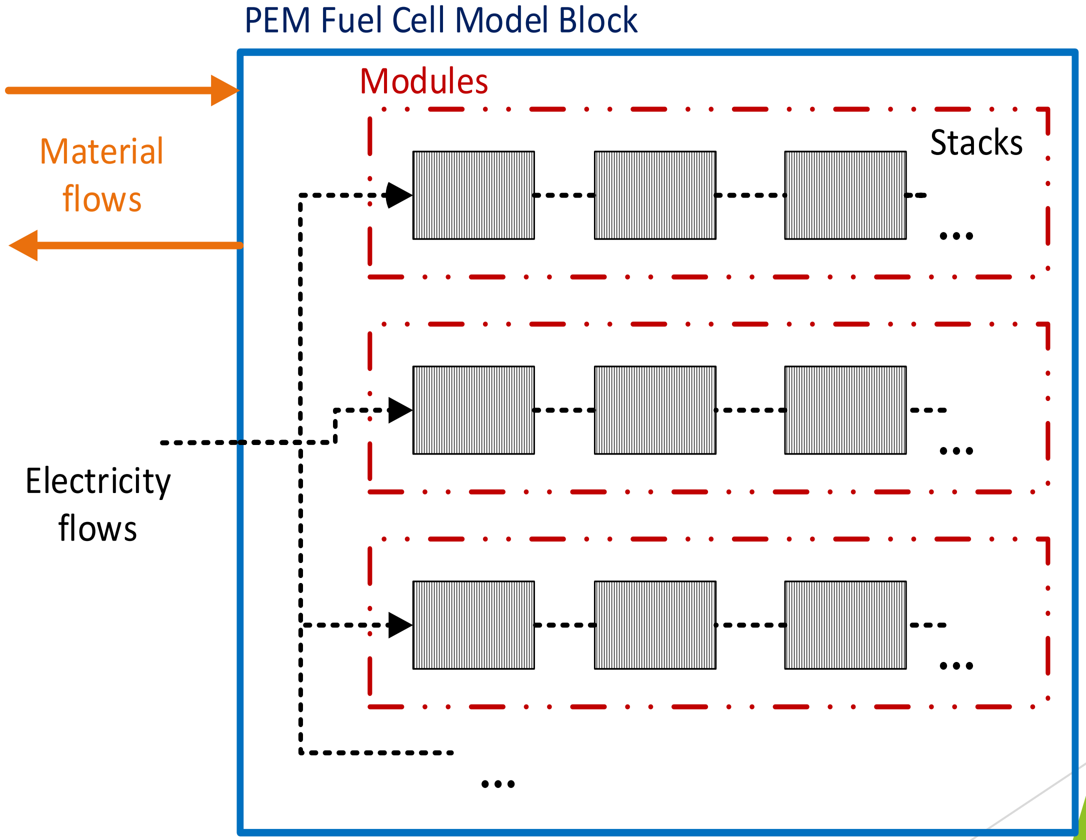
Modelling approach: PEMFC model

- Mass and energy balances are solved to determine cells outlet conditions.
- Pressure drops are a function of the flow rate.
- Cells model is modular: cells can be connected in series and in parallel to reach the desired power.



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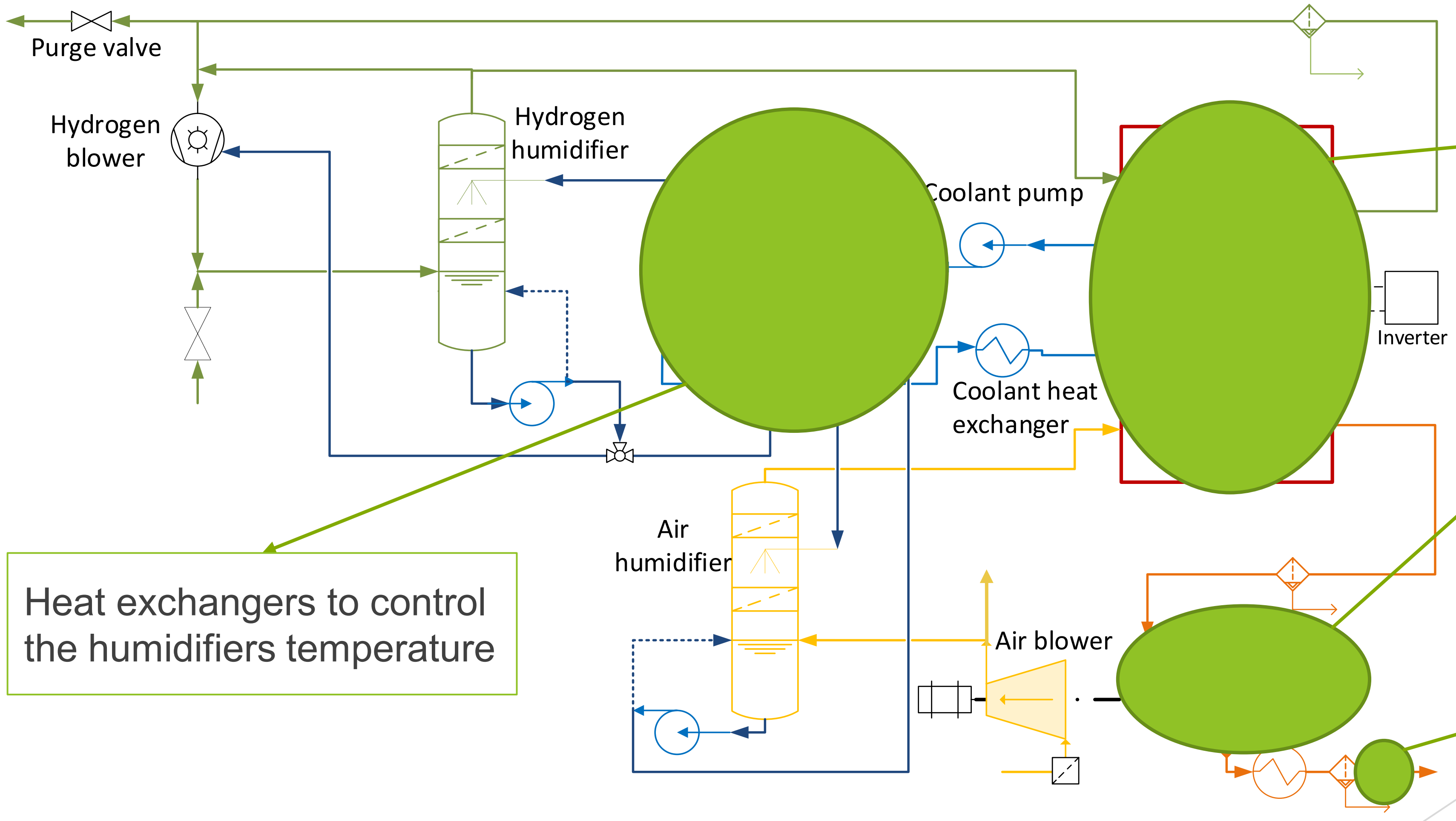
Modelling approach: main BoP components



100 kW PEMFC unit

Two options:

- no air expander
- with air expander
  $\eta_{isentropic}$ = 80%
  $\eta_{mechanical}$ = 90%

Heat exchangers to control the humidifiers temperature

Backpressure valve to pressurise the system

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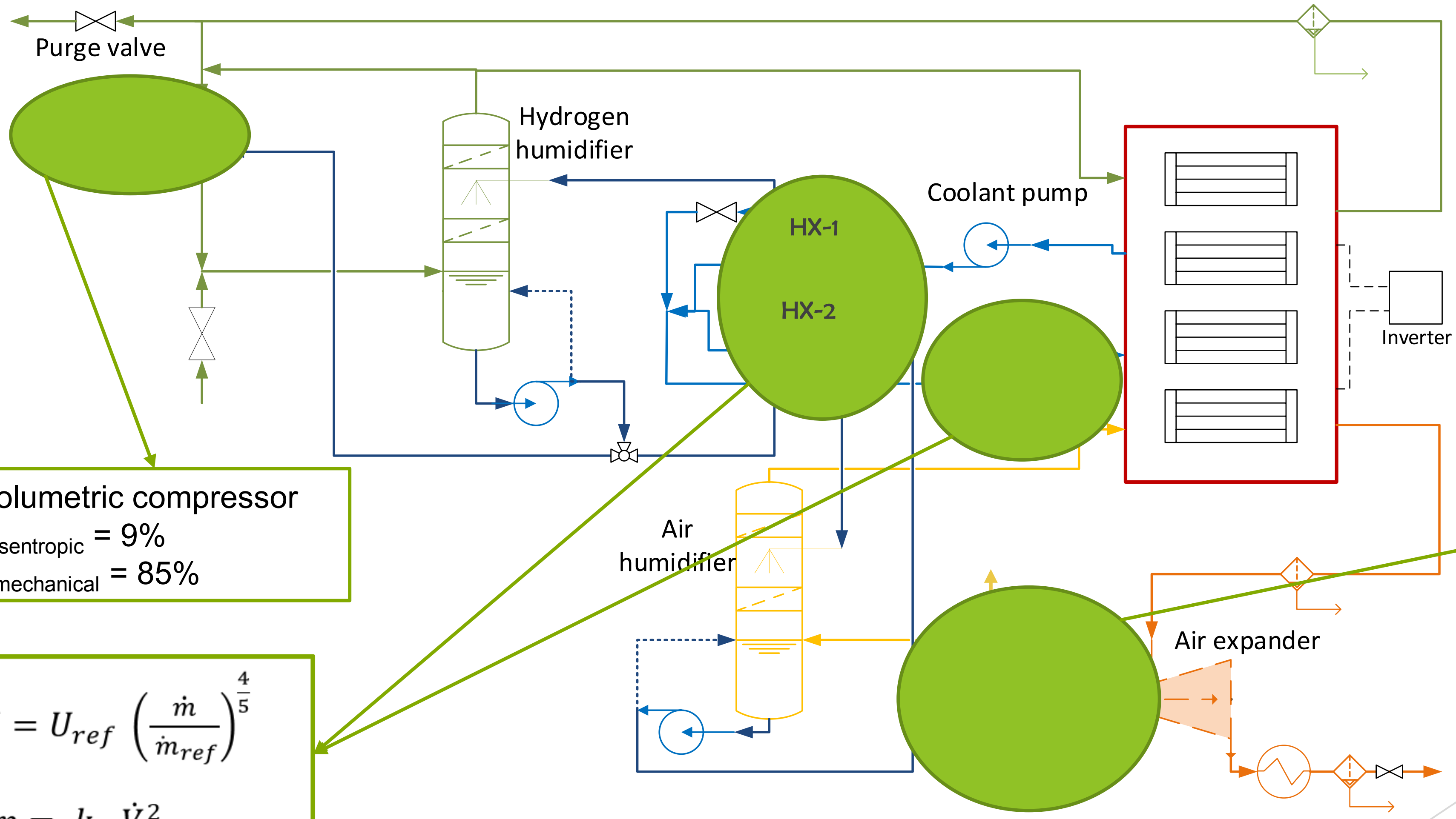
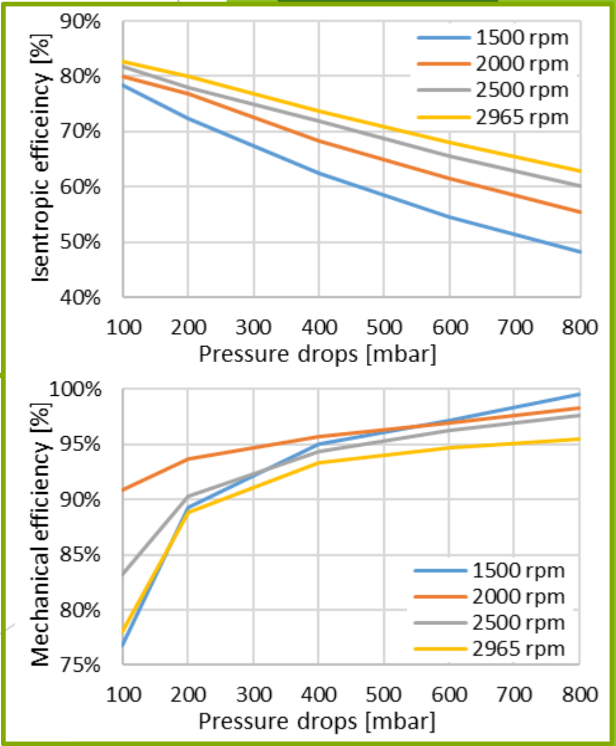
Modelling approach: main BoP components



Volumetric compressor
$\eta_{isentropic}$ = 9%
$\eta_{mechanical}$ = 85%

$$U = U_{ref}\left(\frac{\dot{m}}{\dot{m}_{ref}}\right)^{\frac{4}{5}}$$

$$\Delta p = k \cdot \dot{V}^2$$



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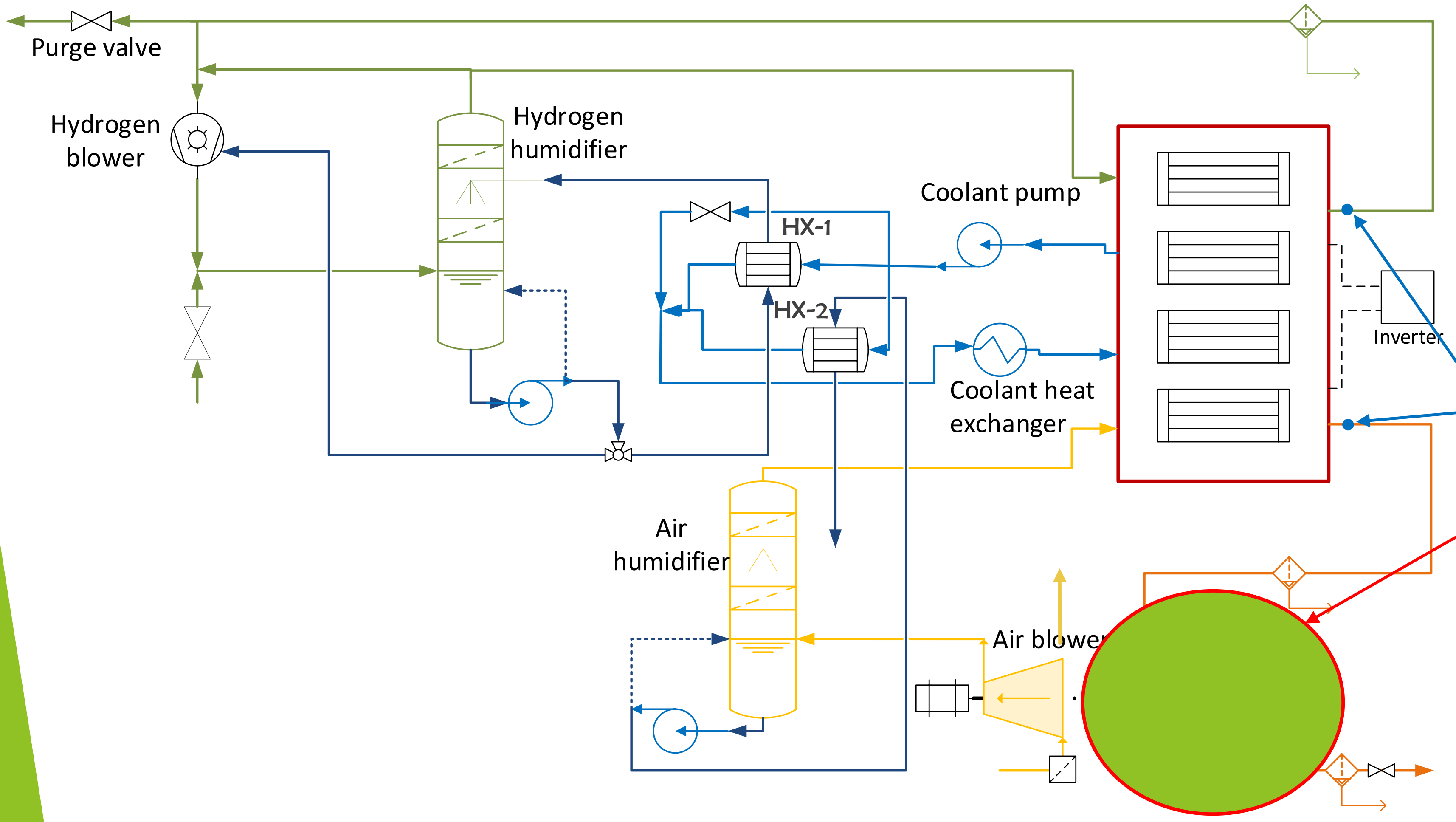
Simulations



- Range of currents between 20% and 150% of the nominal current value (1 A/cm^2).
- Different stack backpressure and plant configuration:

Case 1	Case 2	Case 3	Case 4
Ambient pressure	Ambient pressure	Pressurised (0.6 bar_g)	Pressurised (0.6 bar_g)
No expander	With expander	No expander	With expander

- Constant air and fuel ratio to stoichiometry.
- Variable coolant flow rate.

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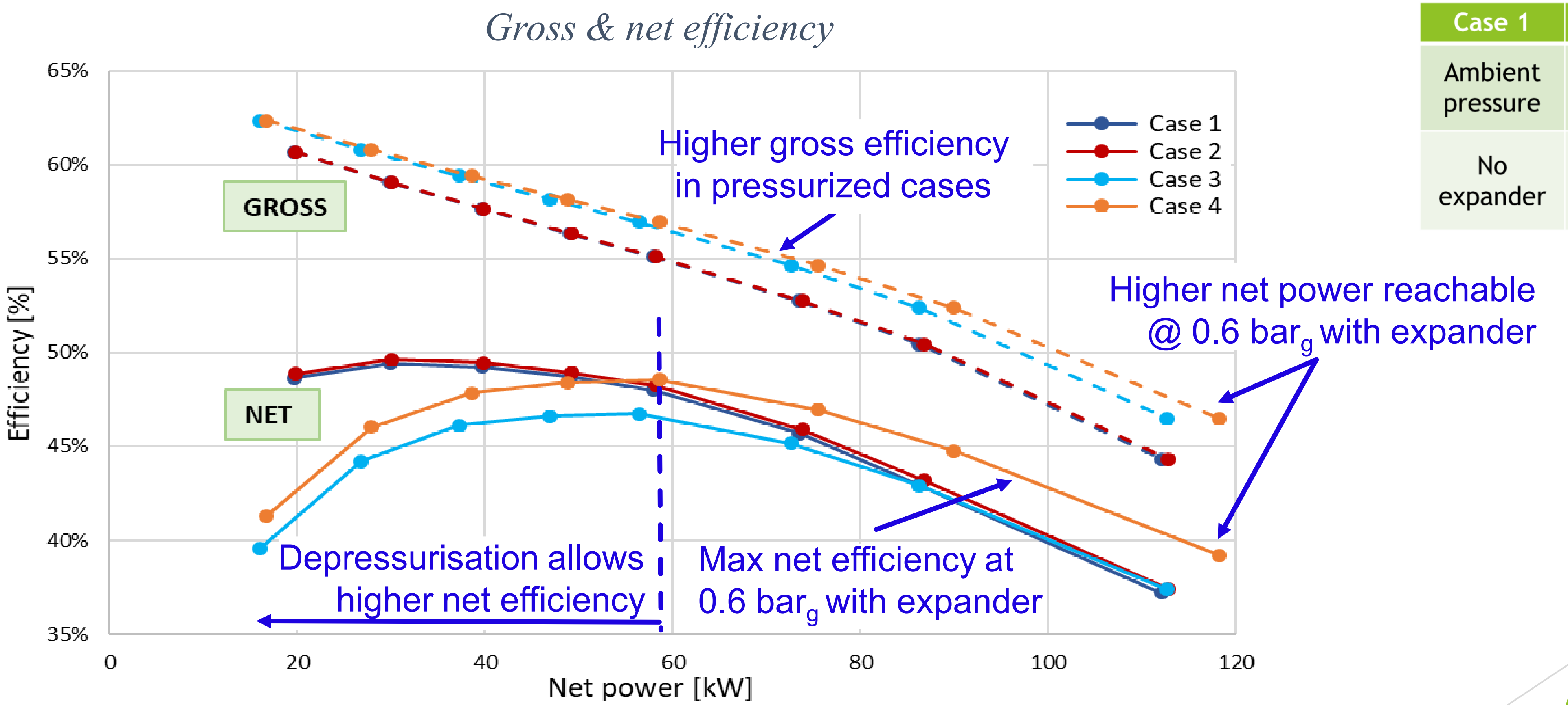
Simulations results



Case 1	Case 2	Case 3	Case 4
Ambient pressure	Ambient pressure	Pressurised (0.6 bar_g)	Pressurised (0.6 bar_g)
No expander	With expander	No expander	With expander

$$\eta_{GROSS} = \frac{P_{FC}}{m_{H_2} \cdot LHV} \qquad \eta_{NET} = \frac{P_{FC} \cdot \eta_{inverter} - P_{auxiliaries}}{m_{H_2} \cdot LHV}$$

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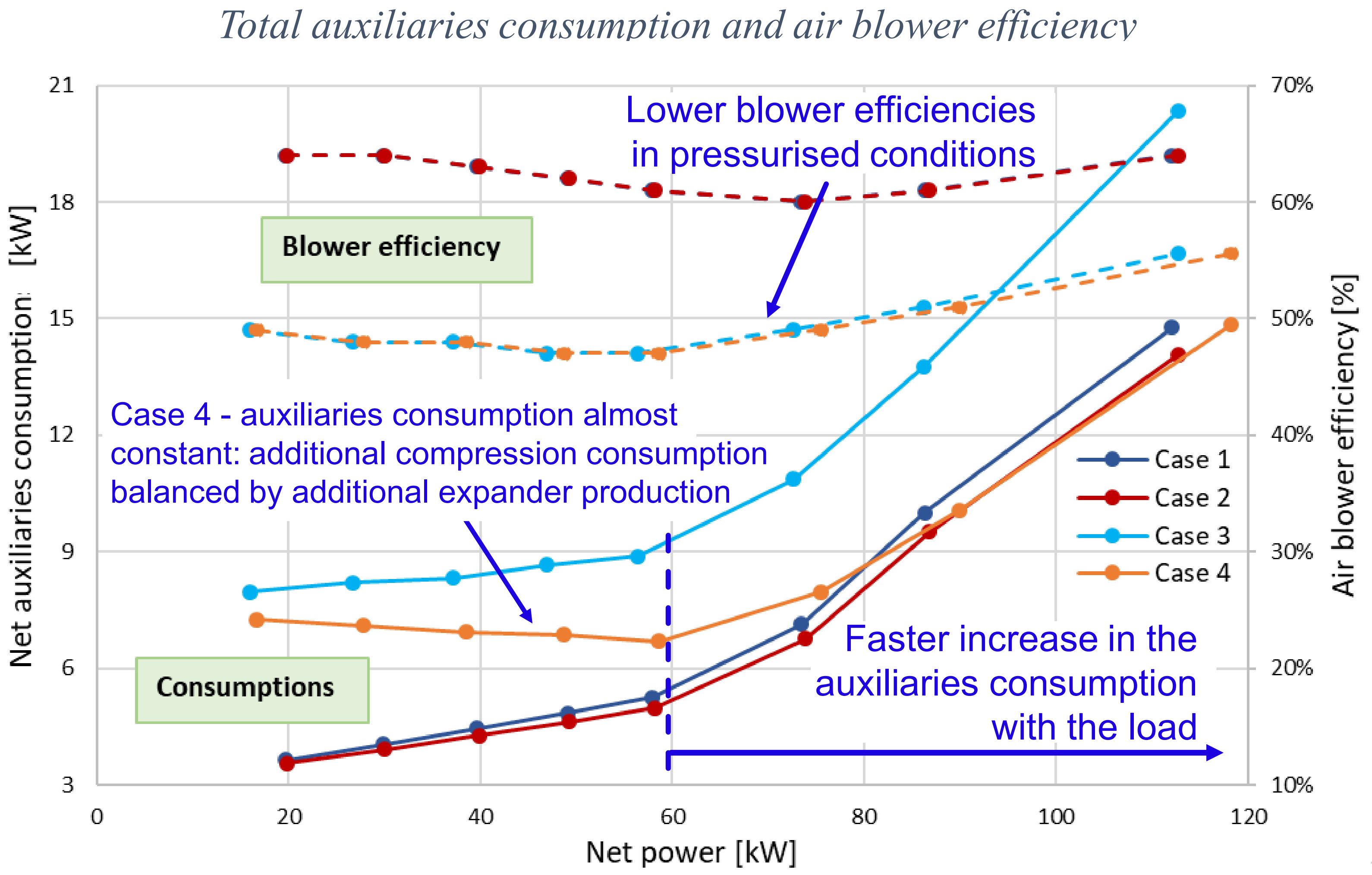
Simulations results



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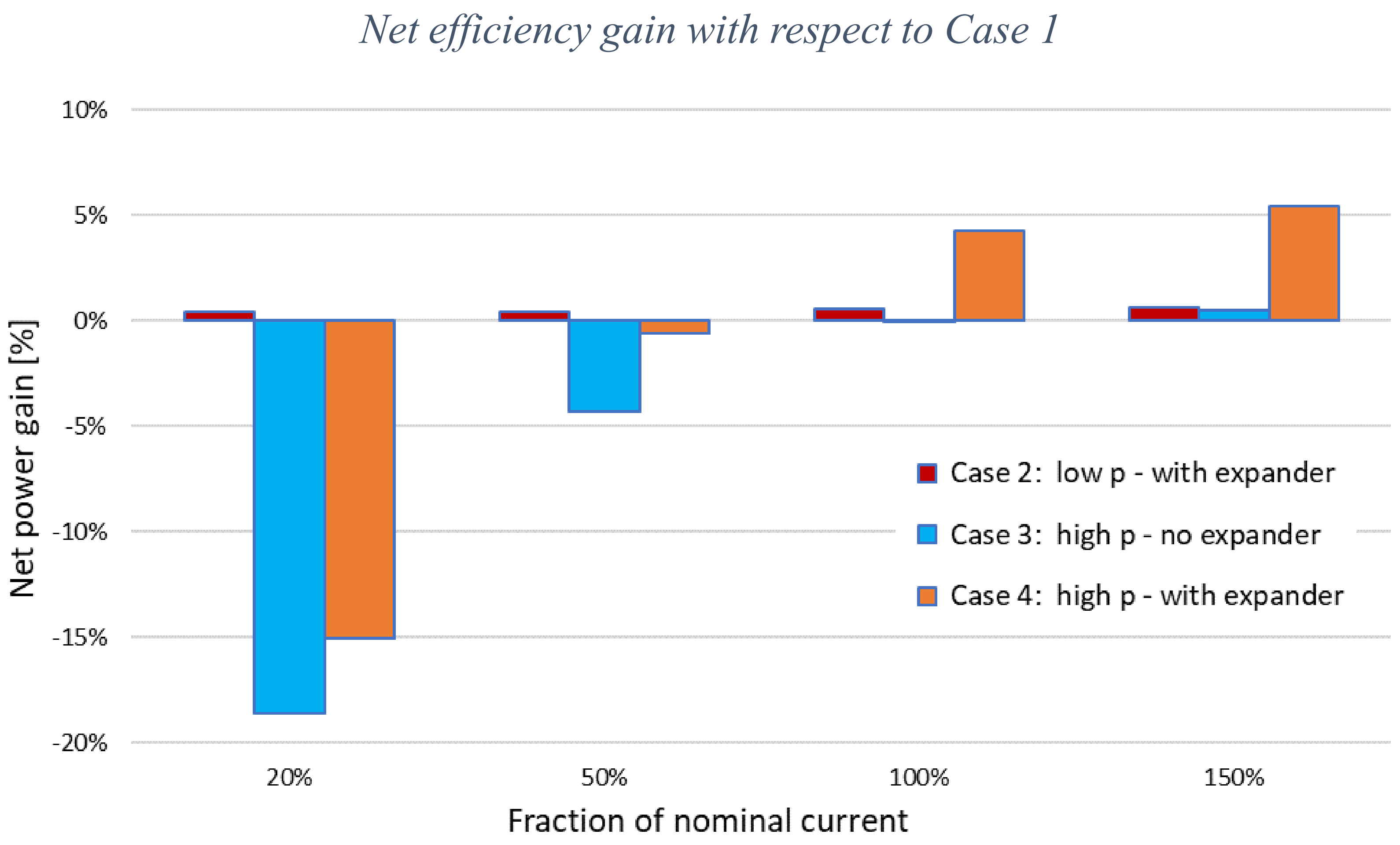

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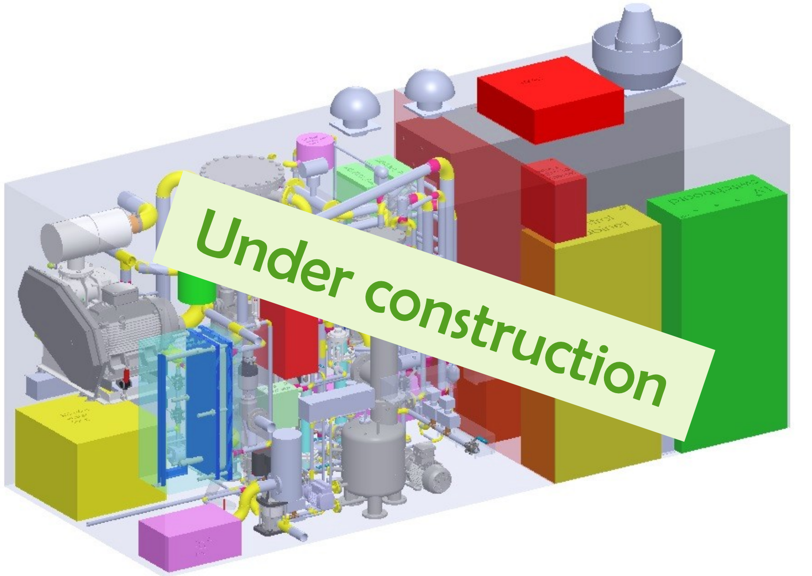
Conclusions and future work

- The stationary model of the PEM FCPP has been realized and has allowed to:
  - support the decision of Grasshopper 100 kW pilot plant configuration
  - identify the operating condition maximising the plant performances at different load
  - support the definition of an optimized plant control strategy.

- Future work will consider:
  - development of new stacks and MEAs with improved performances
  - substitution of the blower with a more efficiency radial compressor to decrease the electrical losses
  - set up of a dynamic model of the pilot plant to further help in the optimization of the operation strategy.



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THANK YOU

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Nominal operating conditions

Stack nominal operating conditions	
Nominal current density	1 A/cm^2
Air ratio to stoichiometry	2
Hydrogen ratio to stoichiometry	1.5
Air / H2 average RH over the stack	100 %
Stack backpressure	0.1 bar$_g$
Stack temperature	70 °C
Coolant temperature gain over the stack	10 °C

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