Power distribution in fuel cell and battery electric aircraft

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Agenda

1. Electrification of aircraft
2. Power distribution systems
3. Multi-objective vector modulation
4. Experimental validation
5. Conclusions

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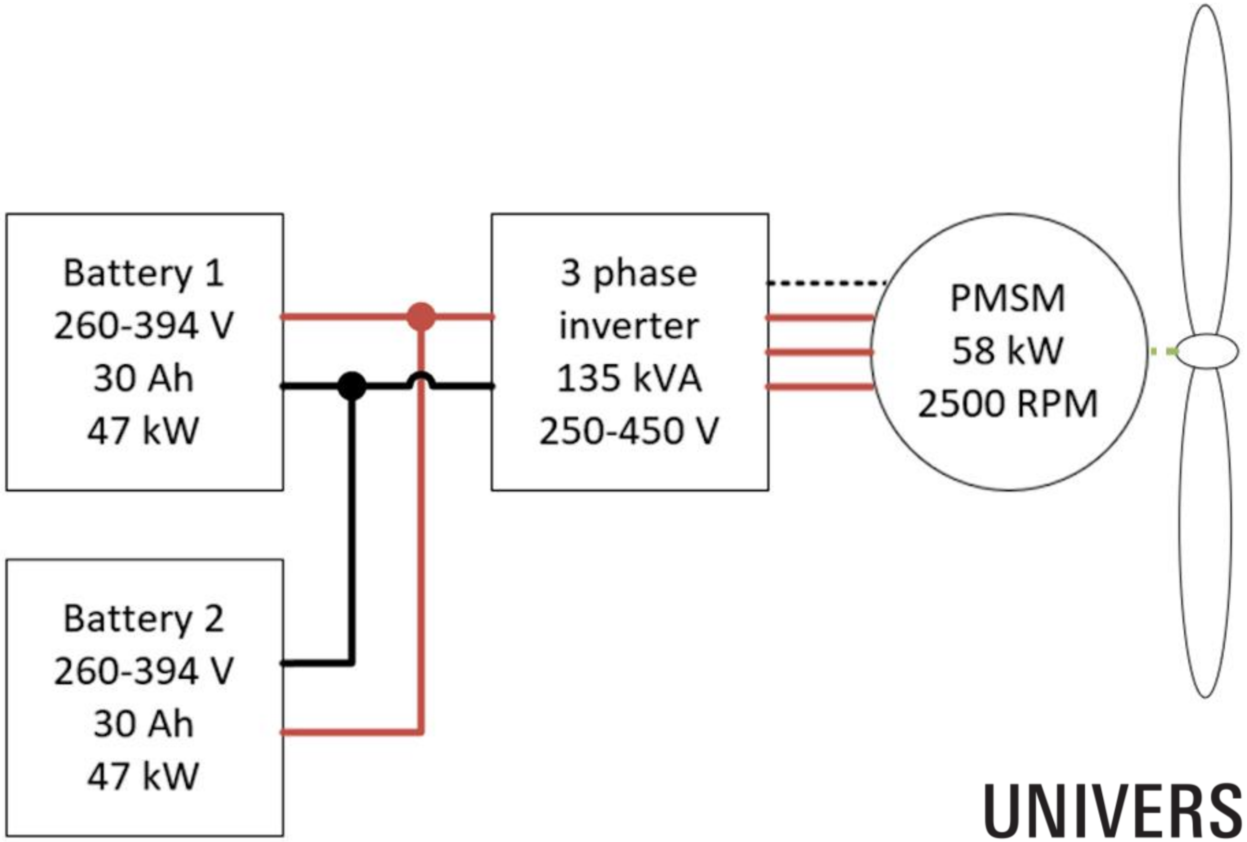
Electrification of aircraft

Pipistrel Velis Electro of NLR, retrieved from: *https://www.nlr.nl/aandachtsgebieden/ strategische-themas-2022-2025/thema-duurzame-luchtvaart/pipistrel/*

- Reducing carbon emissions
- Battery electric prototypes
  - Baseline system
  - Limited flight time
  - Specific energy and power

Existing power distribution system

- Redundant battery packs
- Variable bus voltage
  - SoC and load dependent
- Payload of 172 kg
- Flight range of 50 minutes



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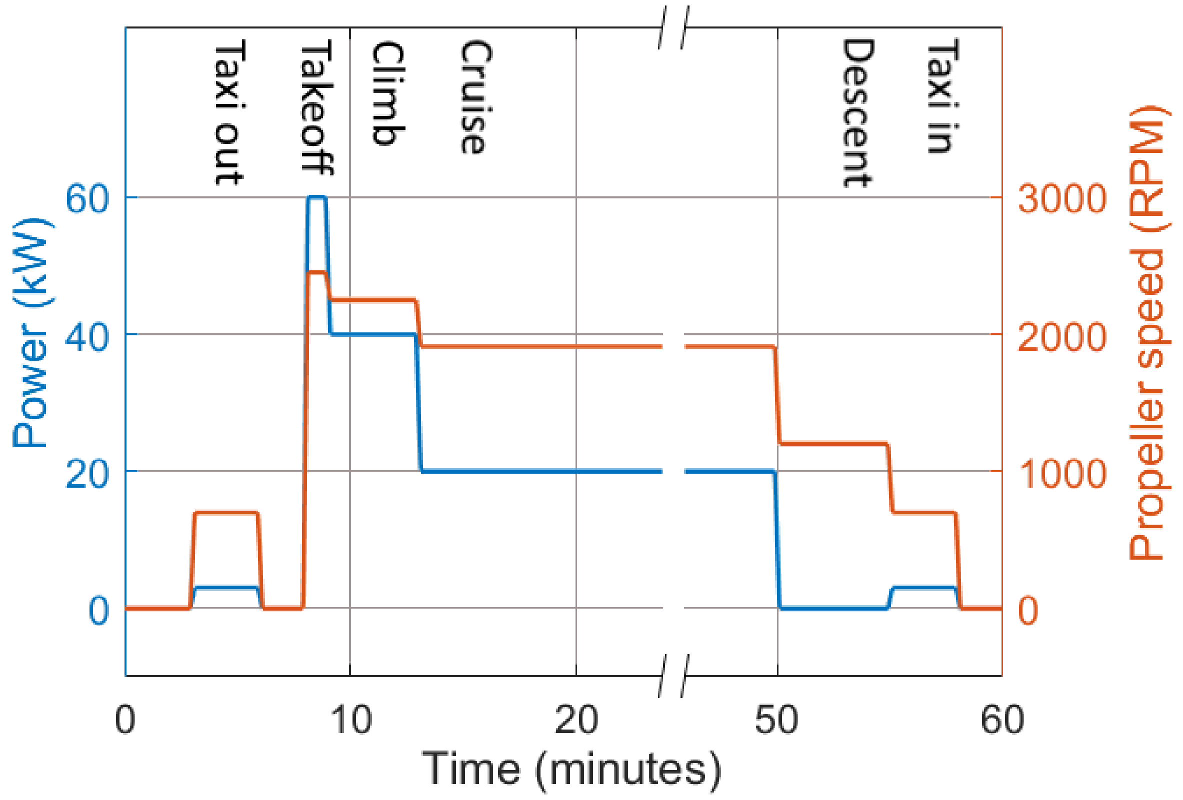
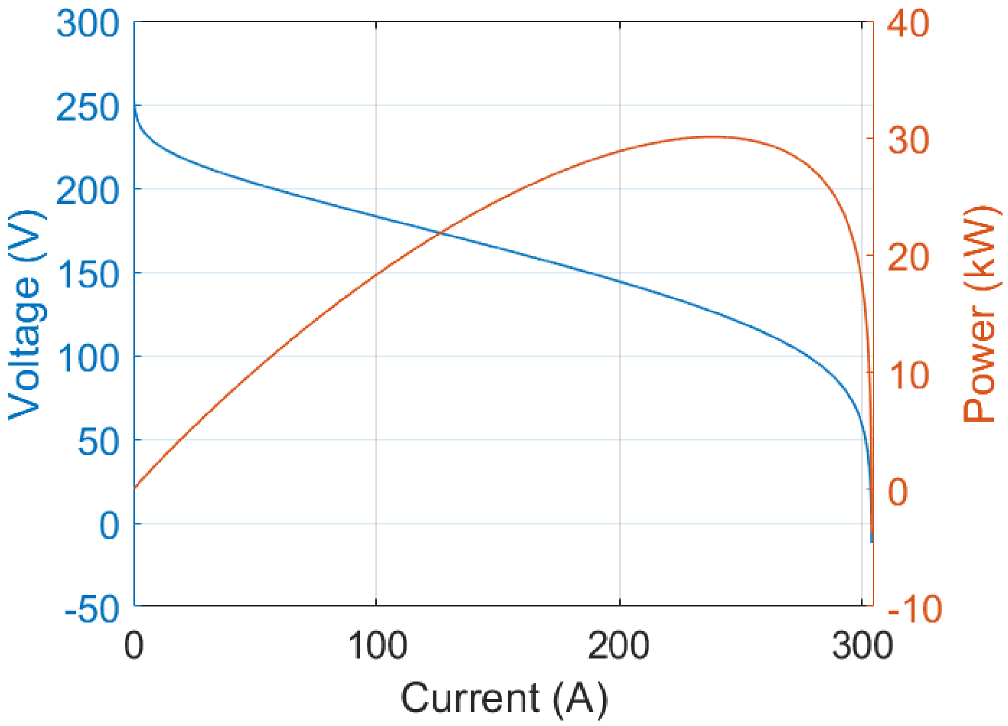
Flight load profile

- Motor power usage
  - Based on flight data
- Battery utilization
  - Peak power
  - Dynamic power
- Fuel cell utilization
  - Cruise power



Hydrogen range extender

- Independent energy and power
- Load dependent output voltage
- Static loading



Storage type	Weight (kg)	Energy (kWh)	Power (kW)
Battery pack	72	12	40
H_2 storage	20	100	-
Fuel cell	50	-	30

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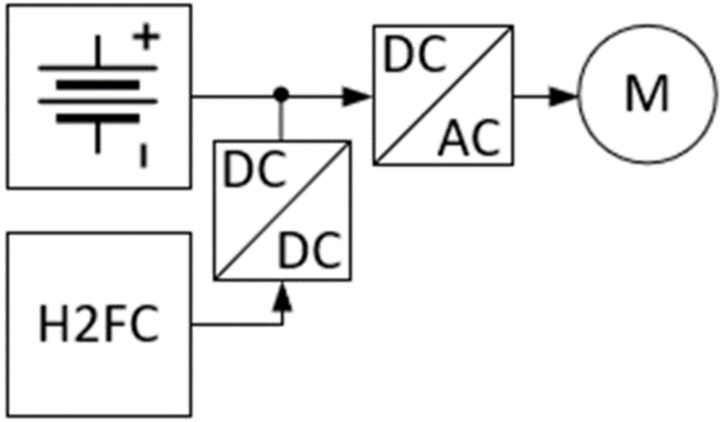
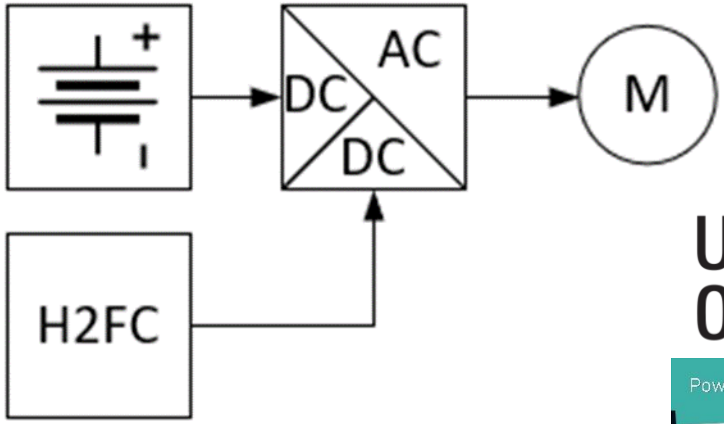
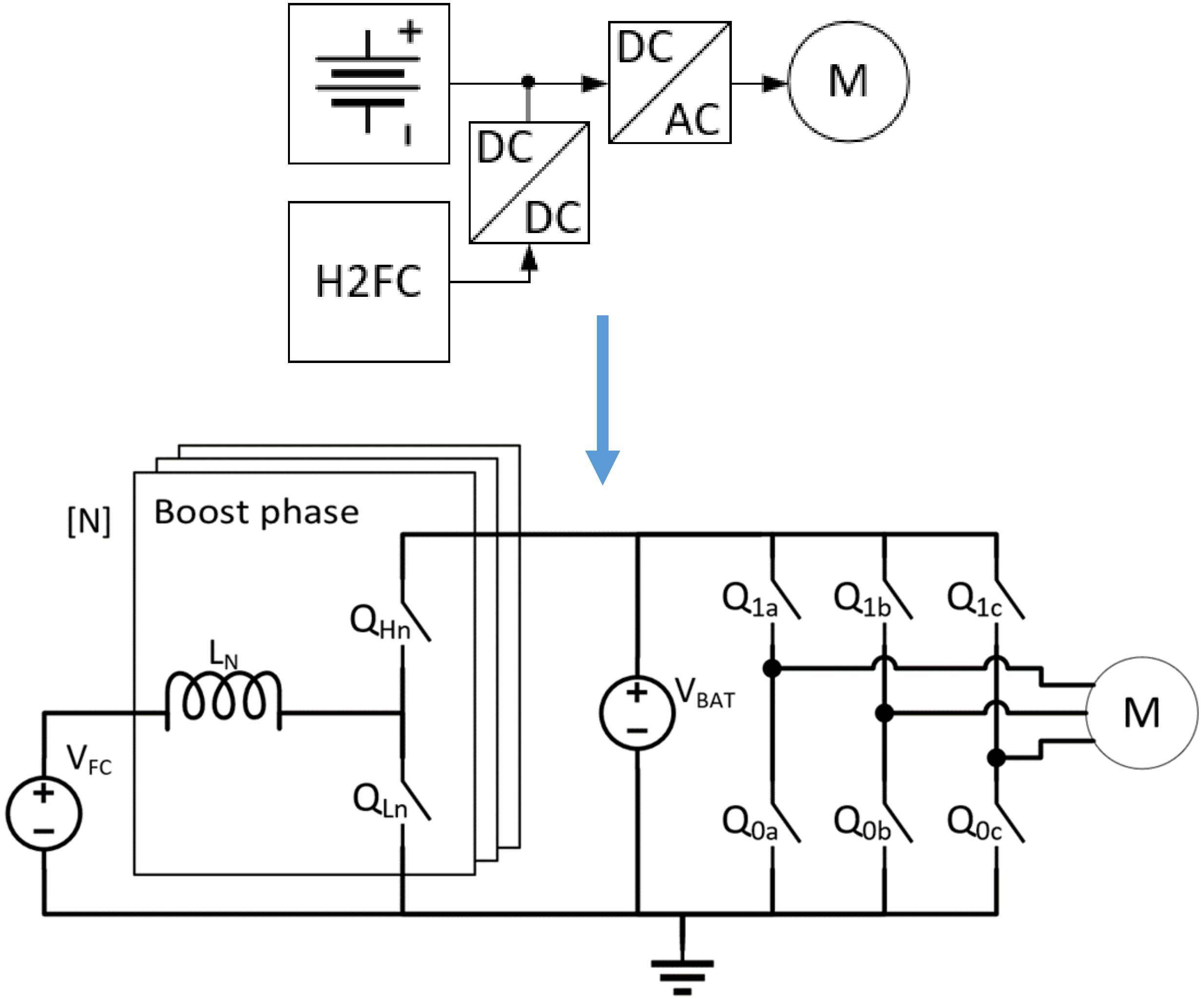
2. Power distribution systems

- Power electronics as interfaces
- Match voltages
- Control power distribution
- Reduce complexity





Benchmark solution



- Two stage conversion
- Interleaved boost converter
- Independent power control
- Commercially available

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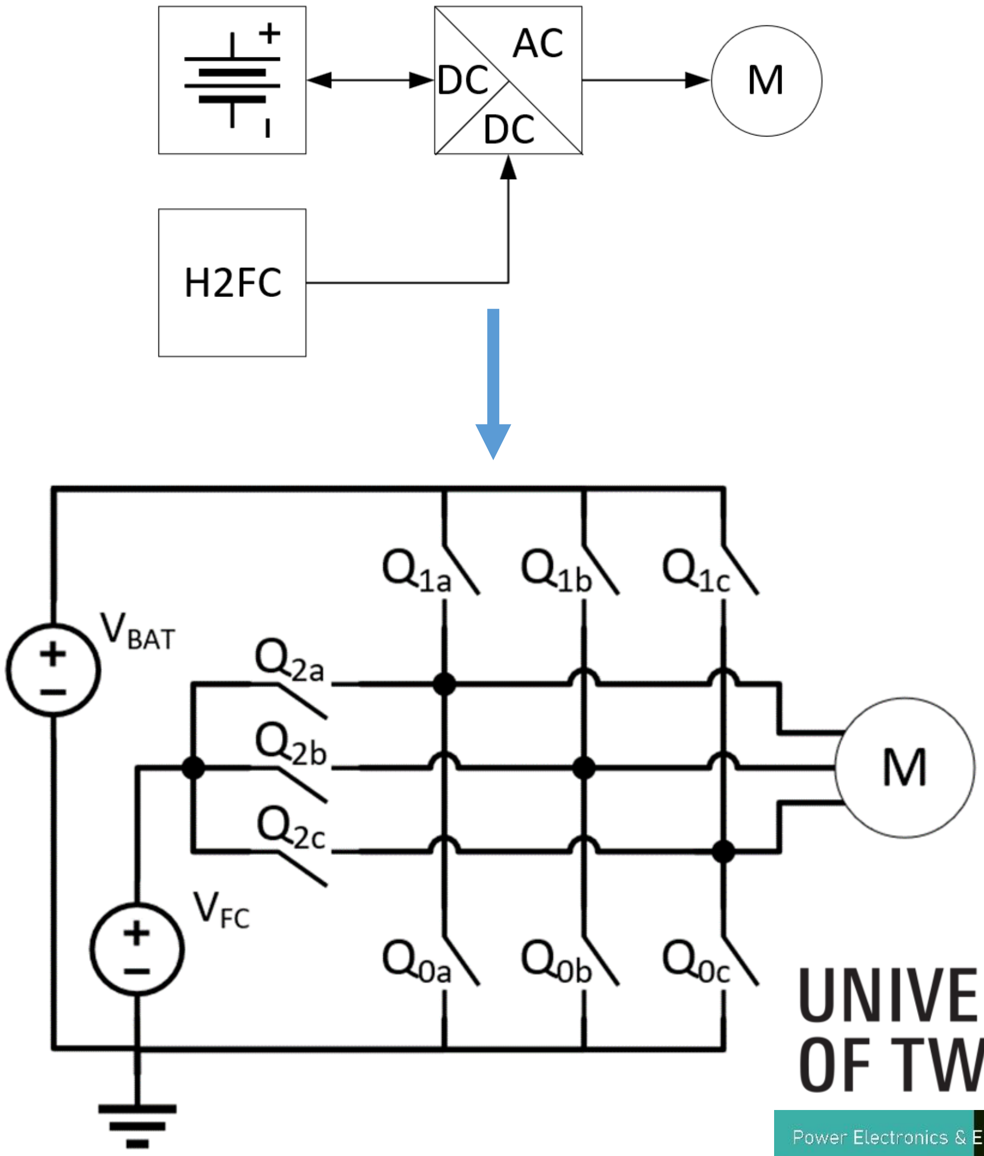
Dual-DC-port inverter

- Modified T-type inverter
- Additional switching states
- Multi-objective vector modulation
- Comparison with benchmark:
  - \+ 3 kg reduction in passive components
  - Similar switching losses
  - − 8% increase in AC current



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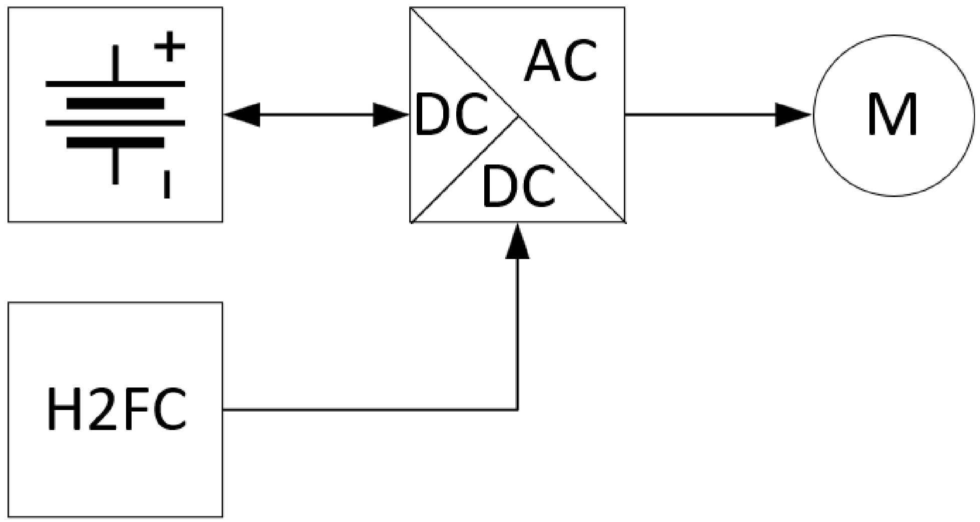
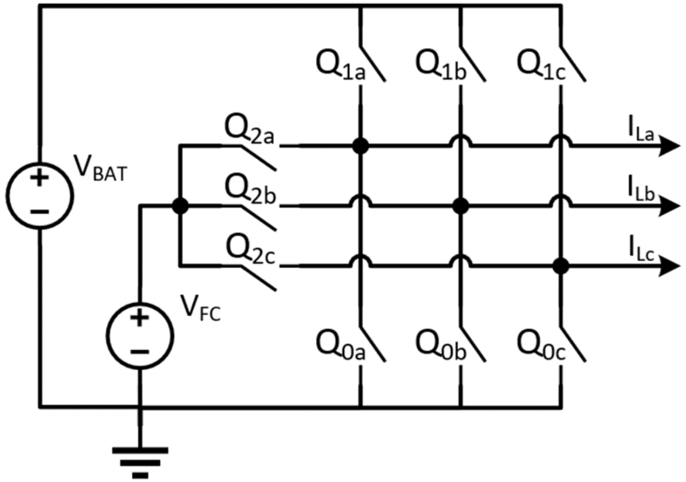
3. Multi-objective vector modulation

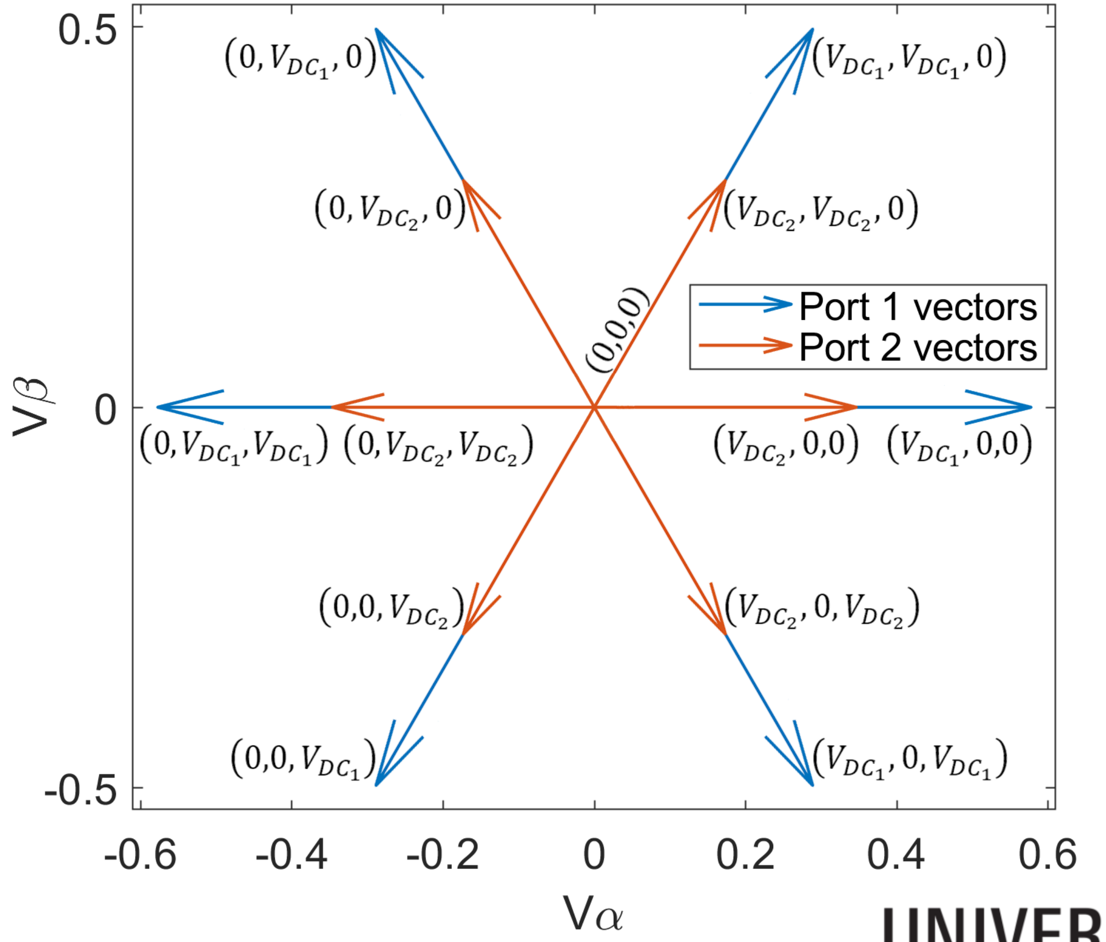
- Generate U_{ref}
  - Set by motor FOC
  - Maximize $|U_{ref}|$
- Distribute DC power
  - Set by energy management
  - Enable battery charging



Vector space

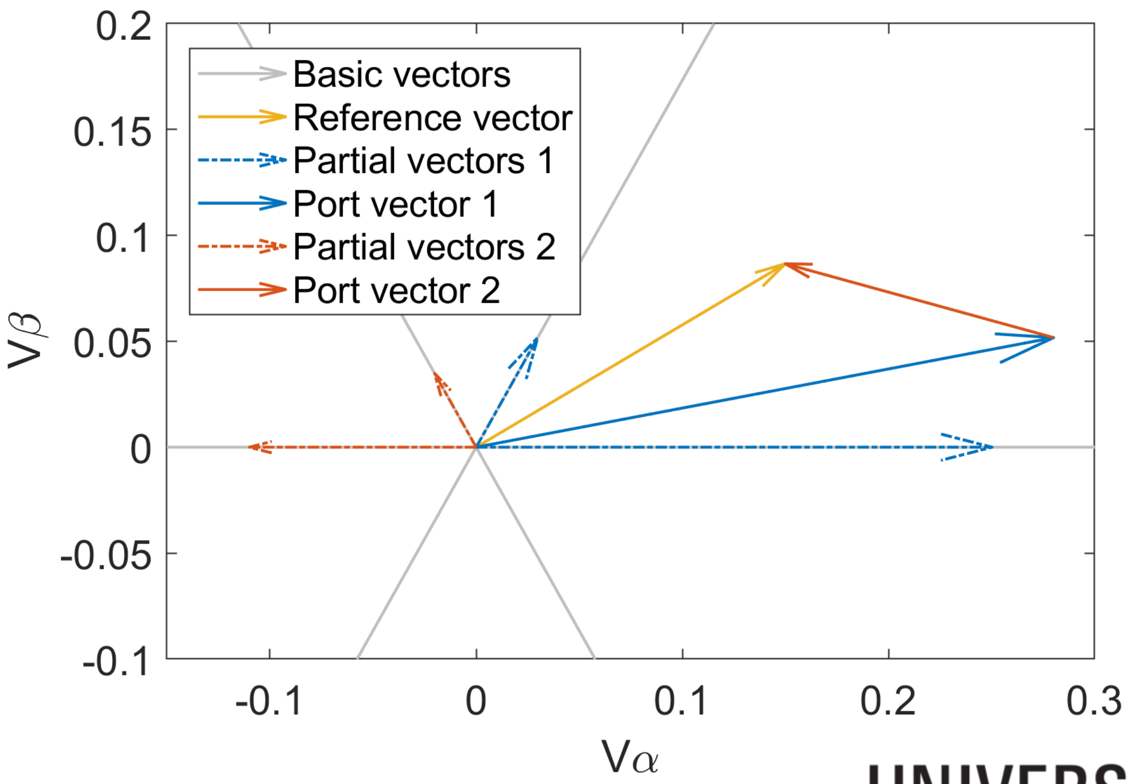
- Unbalanced DC voltages
- 27 possible switching states
  - 13 independent base vectors





Vector space addition

- 13 independent base vectors
- Port vectors
  - $U_1 = d_{1a}U_{1a} + d_{1b}U_{1b}$
  - $U_2 = d_{2a}U_{2a} + d_{2b}U_{2b}$
  - $U_{ref} = U_1 + U_2$
- Limited vector duty cycles
  - $d_{1a} + d_{1b} + d_{2a} + d_{2b} + d_0 \leq 1$



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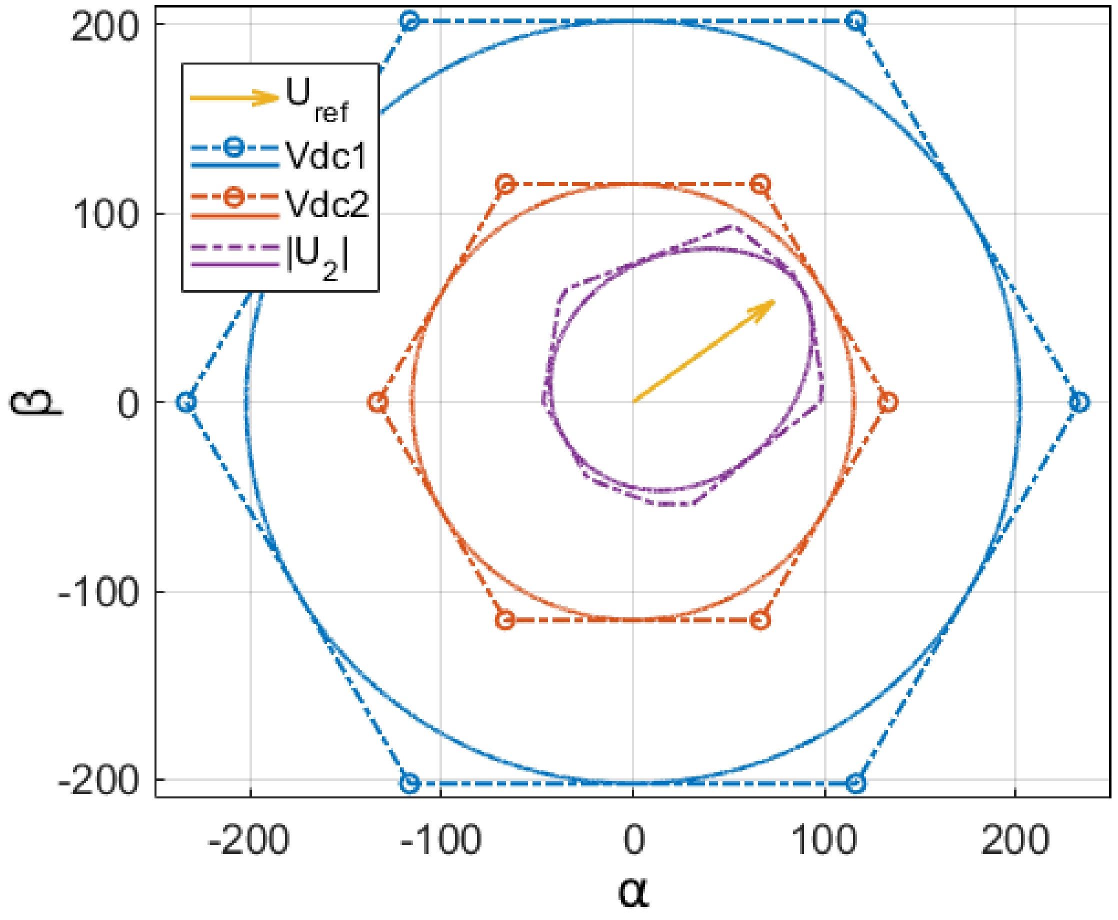
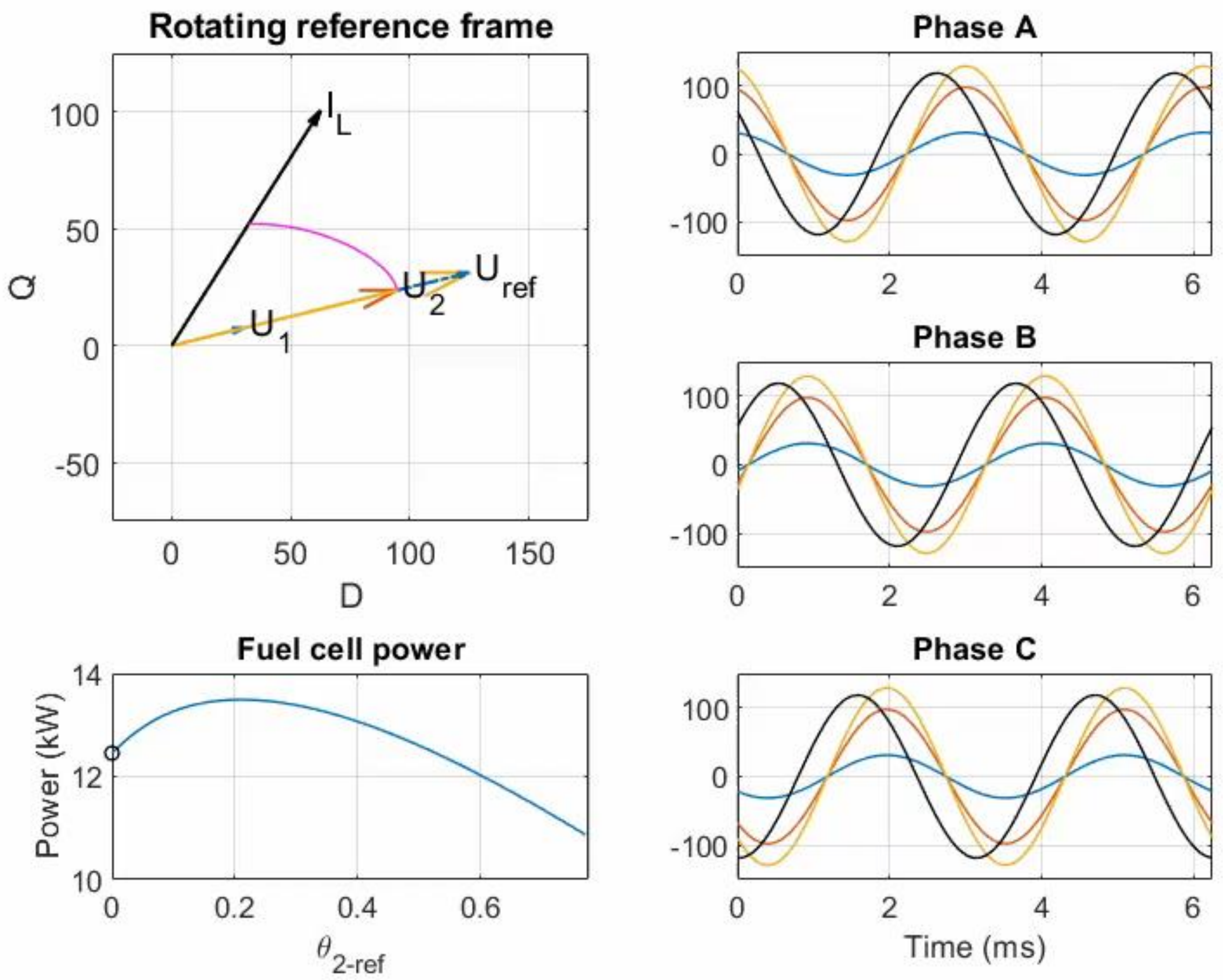
Available vector magnitude

- Single basic vector limit
  - $|U_x| \leq \frac{2}{3} V_{DCx}$
- Uniform limit of one port
  - $|U_x| \leq \frac{1}{\sqrt{3}} V_{DCx}$
- Shared vector limit
  - $\frac{|U_1|}{\frac{V_{DC1}}{\sqrt{3}}} + \frac{|U_2|}{\frac{V_{DC2}}{\sqrt{3}}} \leq 1$



Available port power

- Larger PF when θ_{I-2} is small
- Larger $|U_2|$ when θ_{2-ref} is small
- P_{FC} maximized between angles
  - State dependent optimum
  - Approximated with equations



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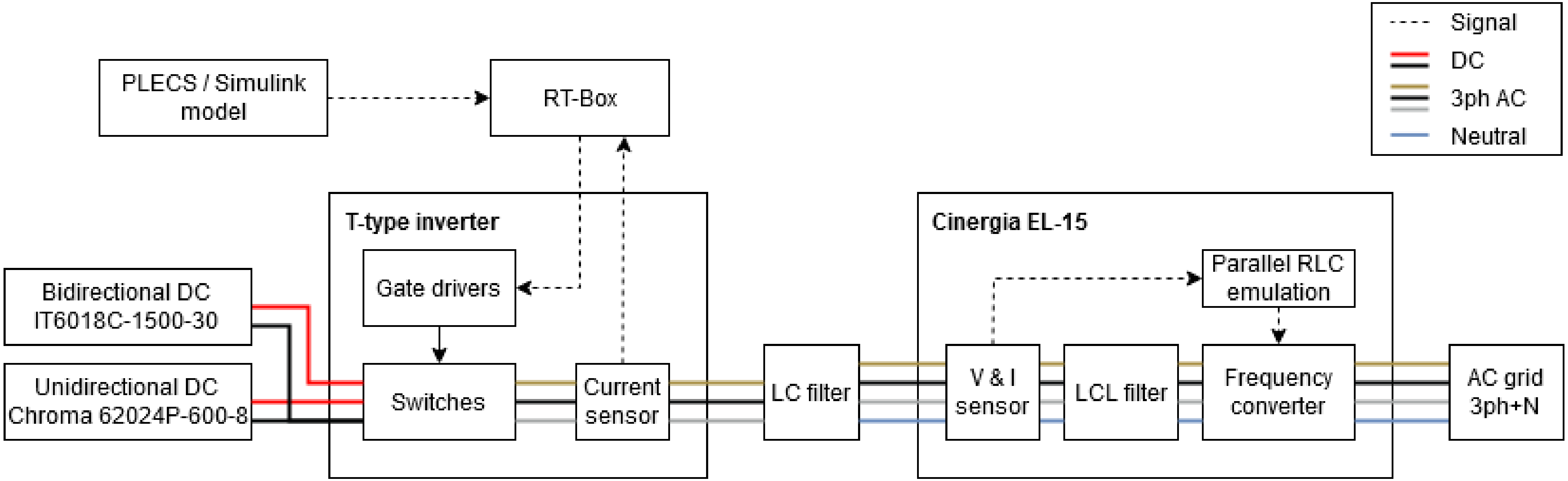
4. Experimental validation



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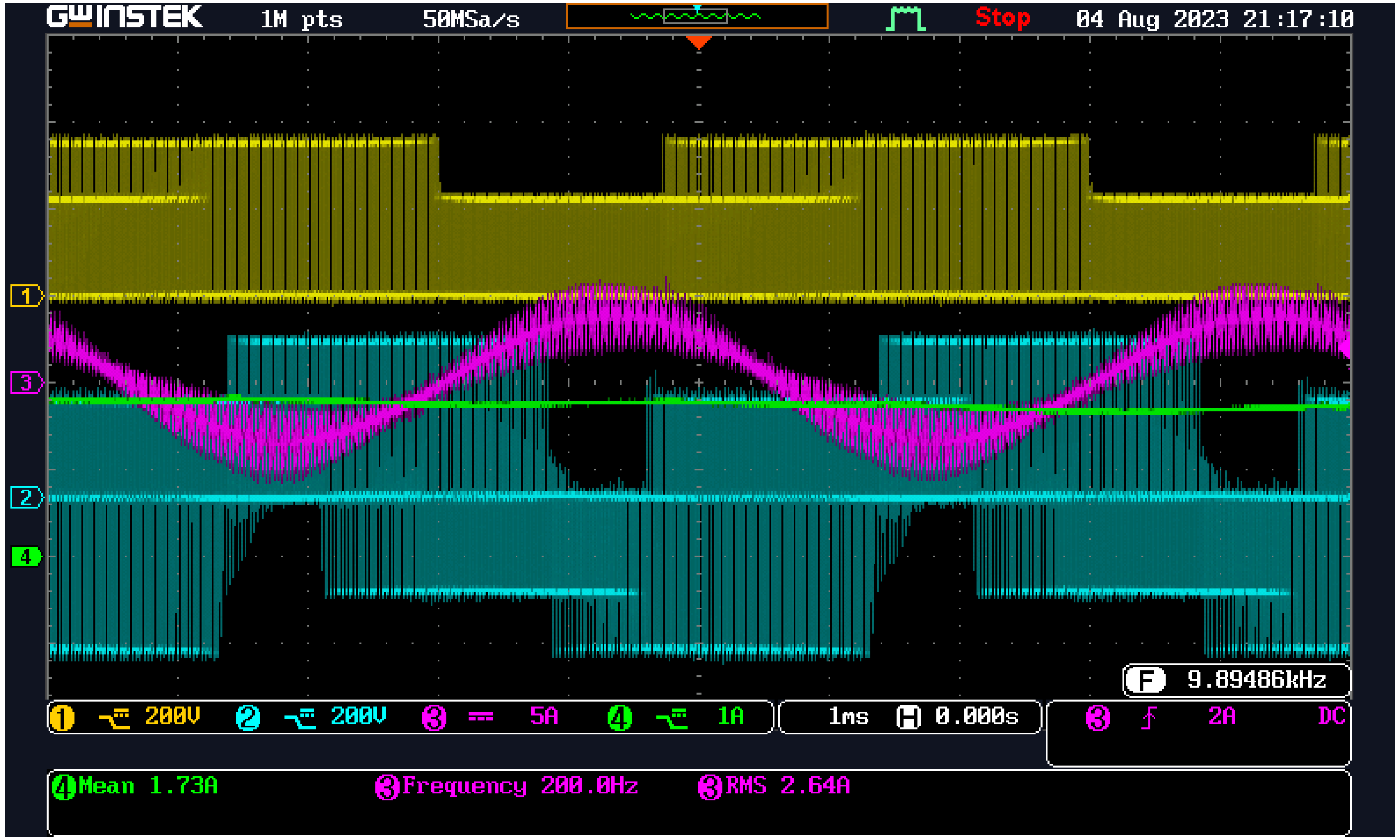
Experimental setup

Experimental results

- Descent scenario
  - 1900 RPM, 0 Nm
  - Low PF
  - 126° from U_1 to U_2

- P_{FC} reference at 375 W
  - 380 +- 8 W output



5. Conclusions

- Successful integration of H2
- Low weight alternative
- Remaining research
  - Efficiency
  - EMC
  - Energy management

Thank you

- Want to know more?
  - Ask your question here
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  - Send me an e-mail:

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