Verbund Hydro Power

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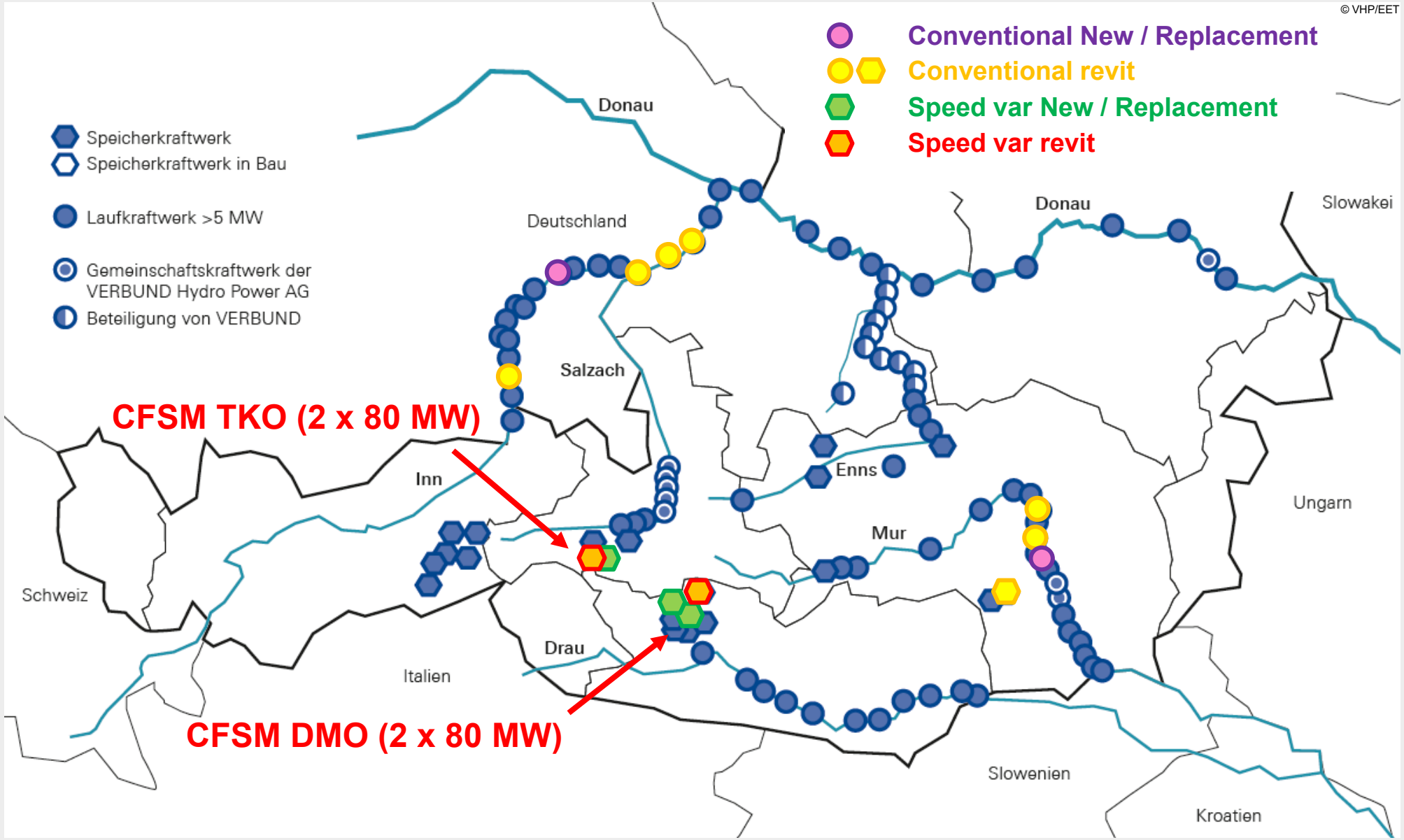
26.06.2023

Verbund

Verbund power plants and recent projects



Commissioned Projects DMO and TKO

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Overhaul Project Malta Oberstufe I

Original Pumped Storage Design

In operation since 1977

2x 60MW synchronous machines
- Pole-changing motor-generator
- (375 - 500 rpm)

Isogyr hydraulic system
- Separated pump and turbine

New Design

After Overhaul 2022 «Efficiency Increase»

2x 80MW Converter Fed Synchronous Machine
- Variable speed operation (240…575 rpm)
- Modular Multilevel Converter

New Motor-Generator

New machine transformer

New reversible pump-turbine

➢ Reuse of existing structures

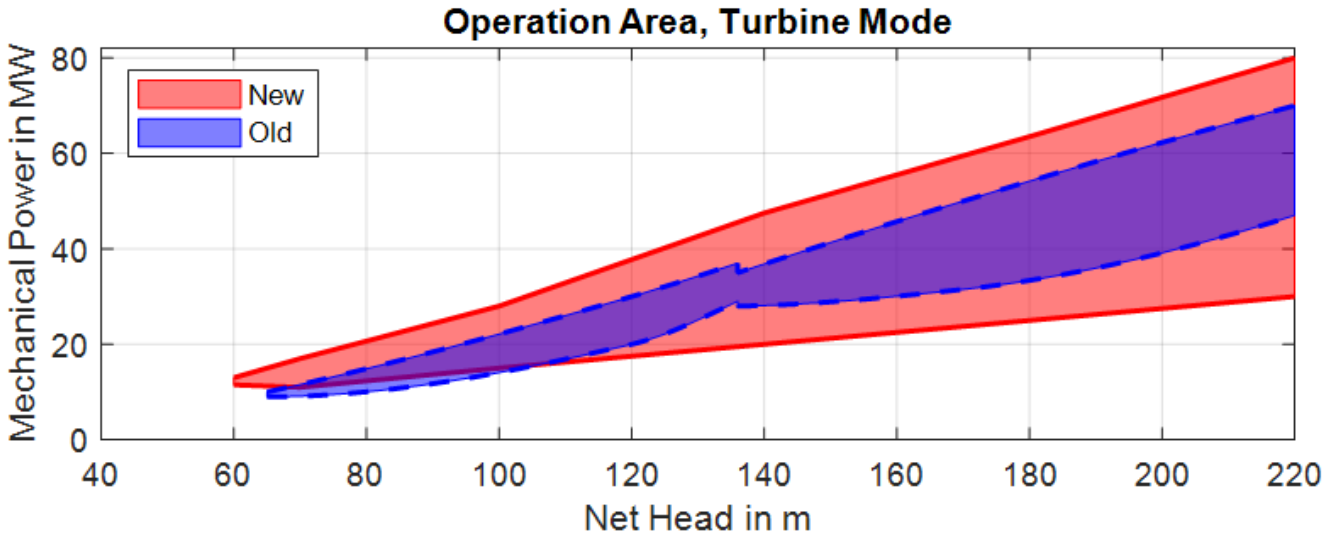
Overhaul Project Malta Oberstufe IV

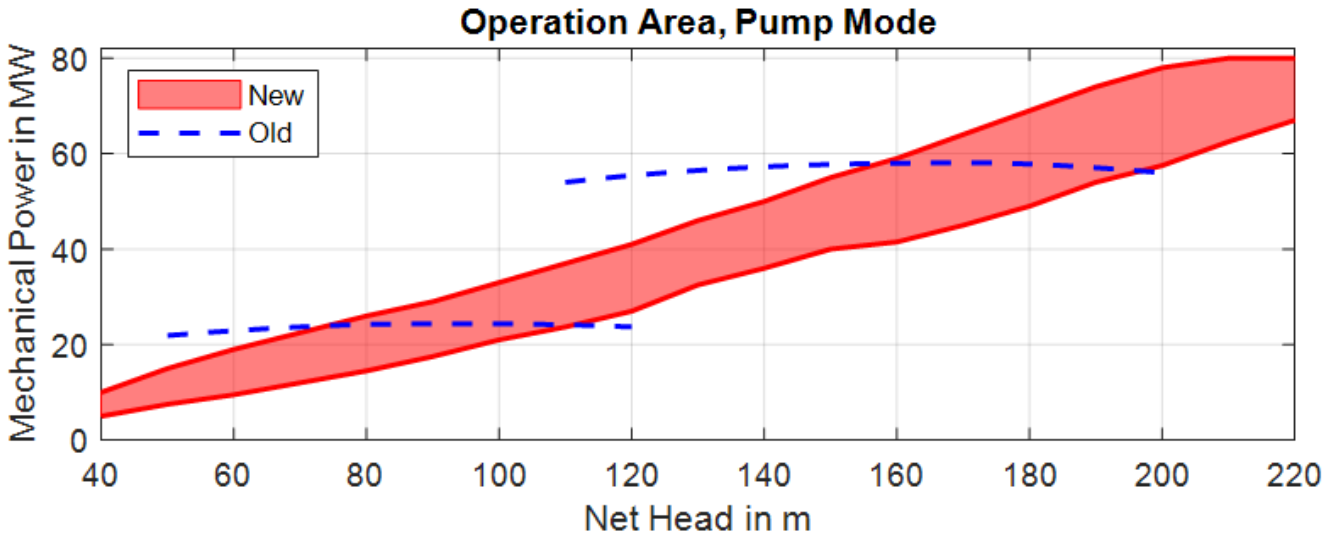
Turbine Mode

- Extended net head
- Wider power range window
- Efficiency improvement around 9% averaged in the operation area

Pump Mode

- Active power control
- Extended head range 40 to 220 m
- Optimized operation for each head
- Efficiency improvement between 15 to 22 %





Overhaul Project Kaprun Oberstufe I

Original Pumped Storage Design

In operation since 1956

2x 65 MW synchronous machine

- 500 rpm
- Head range (288 m – 446 m)
- 56 MW Francis turbines
- 65 MW radial pump

New Design

After Overhaul 2020 - 2022 «Efficiency Increase»

2x 80MW Converter Fed Synchronous Machine

- Variable speed operation (400…730 rpm)
- Voltage Source Inverter

New Motor-Generator

New machine transformer

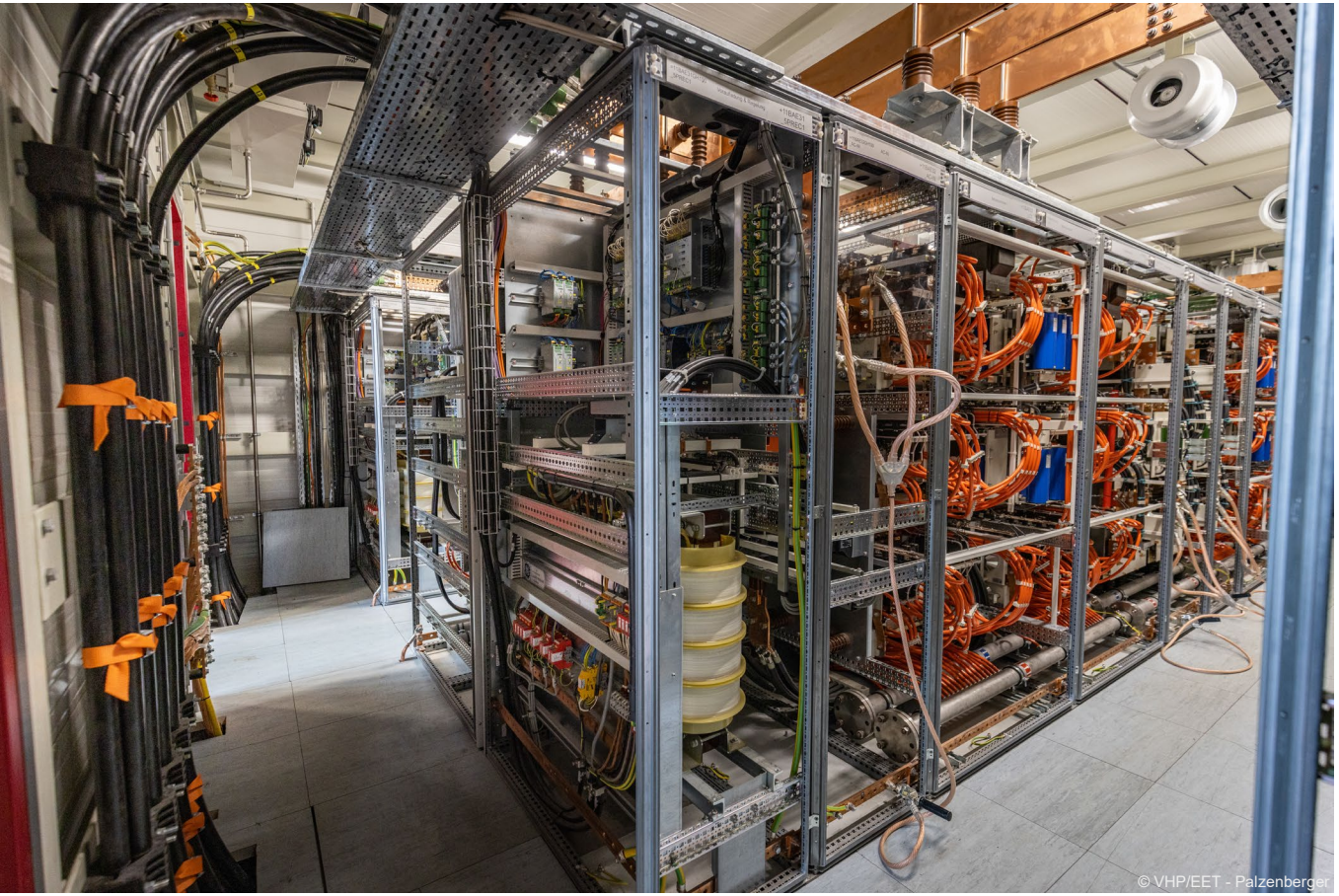
New reversible pump-turbine

➢ Reuse of existing structures

Overhaul Project Kaprun Oberstufe III

Overhaul Project Kaprun Oberstufe IV

Overhaul Project Kaprun Oberstufe V



Technical aspects and operation experience

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Converter Technologies

Voltage Source Converter

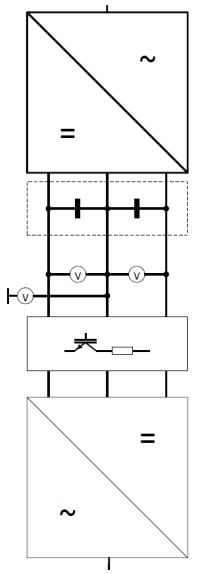
TKO – 3-level converter

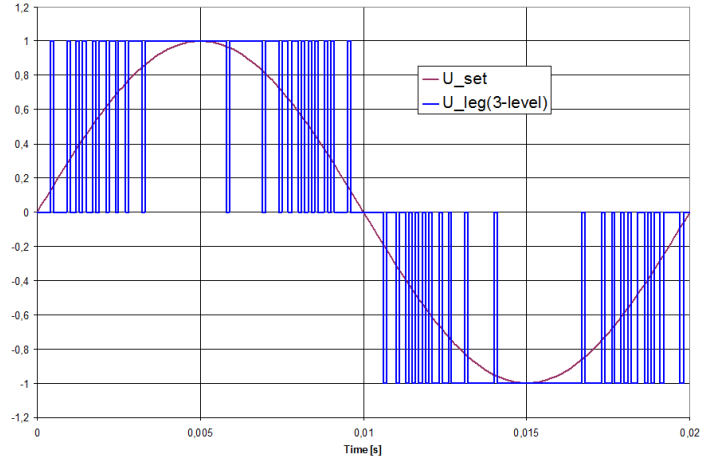
Output voltage 3 conditions
- Aggressive voltage form
- Current ripple

Frequency range
- 0 to 51 Hz (higher with output filter)

Multi-winding transformer necessary

Redundancy on converter level
- Failed output switch takes out converter





VHP/EET/Umprecht – Presentation FAREM

Direct Converter

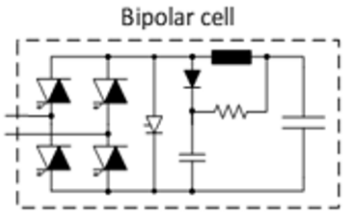
DMO - MMC

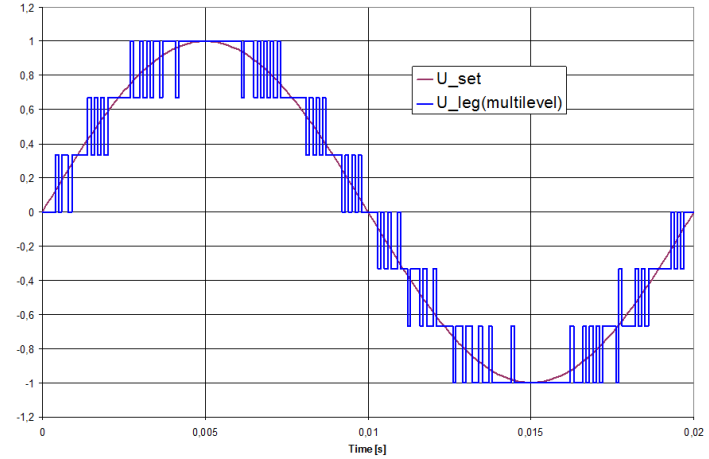
Output voltage smoother
- Depends on number of serial cells

Frequency range
- 0 to ~42 Hz

Possible with two-winding transformer

Redundancy on cell level
- Continued operation with failed cell





VHP/EET/Umprecht – Presentation FAREM

Design Considerations – Power Train

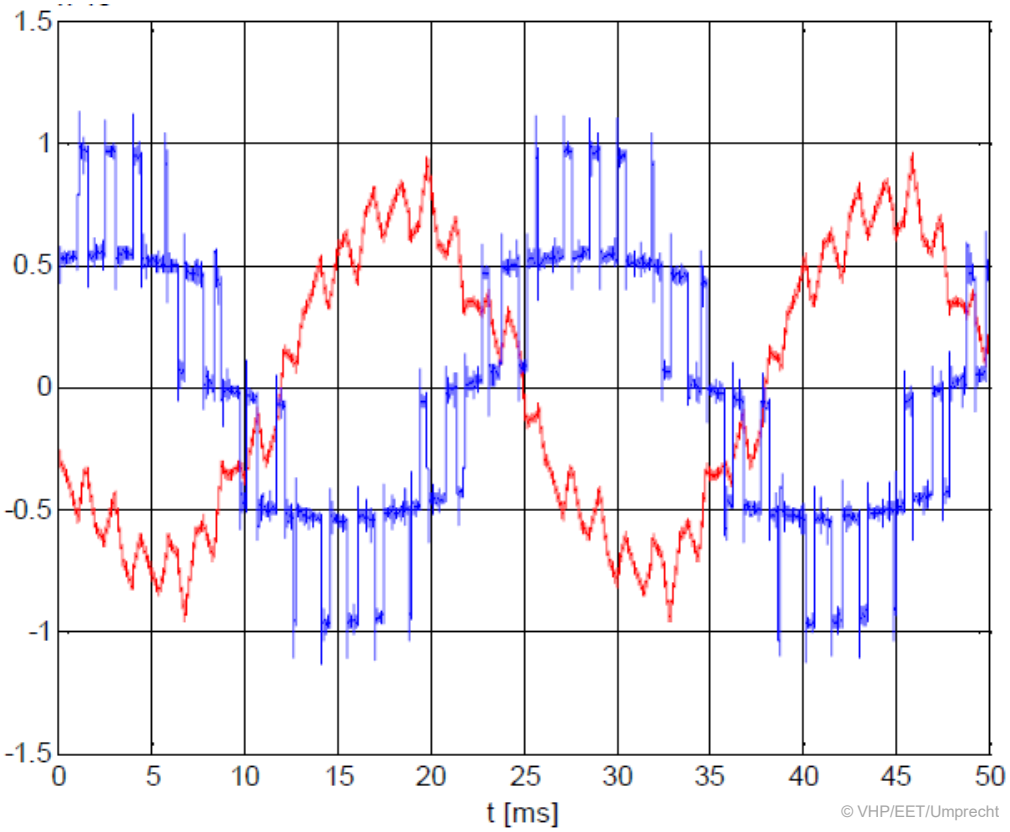
Electrical

Stator voltage form (THD factor, high du/dt)
- Higher insulation stress and particle discharge level
- Capacitive coupling
  - Heating of potential grading
  - Shaft voltage

Stator current form (THD factor, ripple)
- Additional losses and changed loss distribution
- Pulsing moments

Mechanical

Design for speed area
- Eigenfrequencies + Resonances
  - Torsional oscillations
  - Noise emission
  - Vibrations



Operation flexibility

Technology benefit CFSM

Increased area of operation

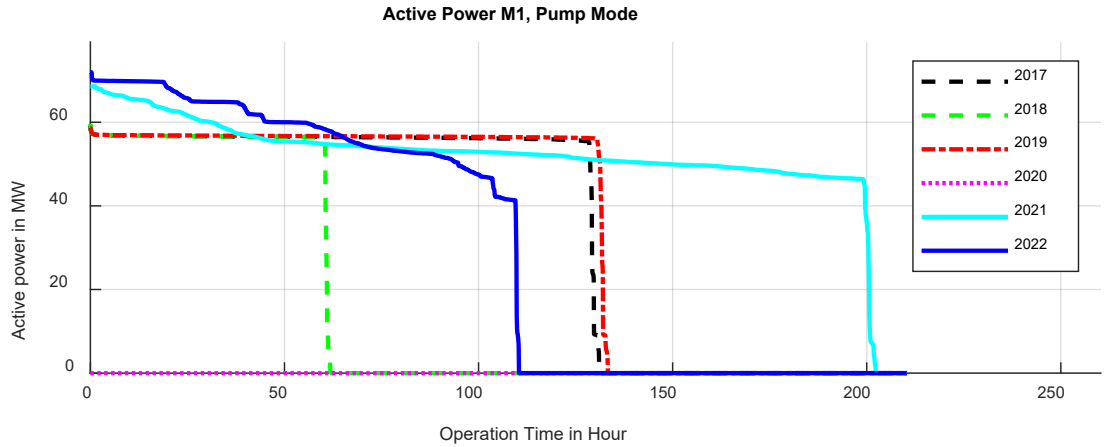
Active power control operation in pump mode

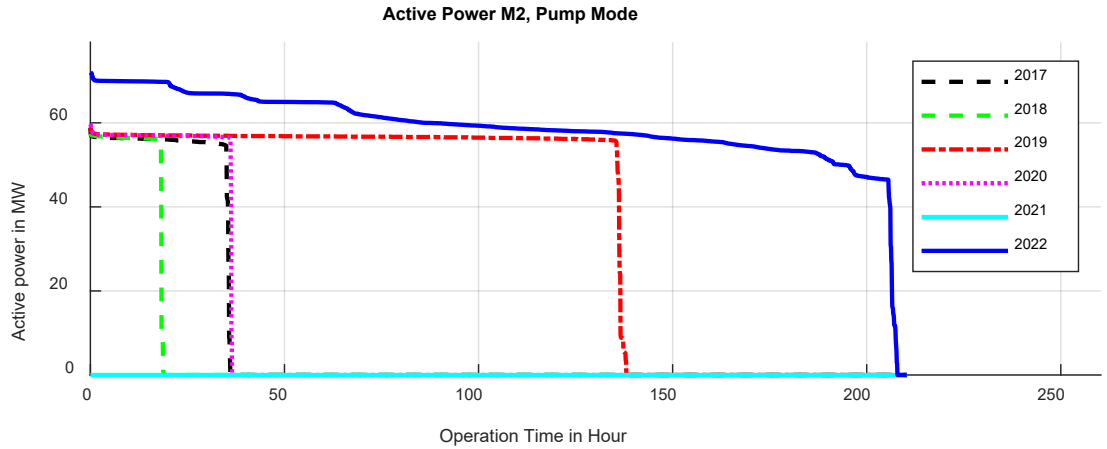
- Provision of grid frequency support
- Participation to primary control possible
- Higher flexibility for unit commitment

Impact on pump operation

Utilization of variable power

- Increased operational hours
- Extended operation time per start





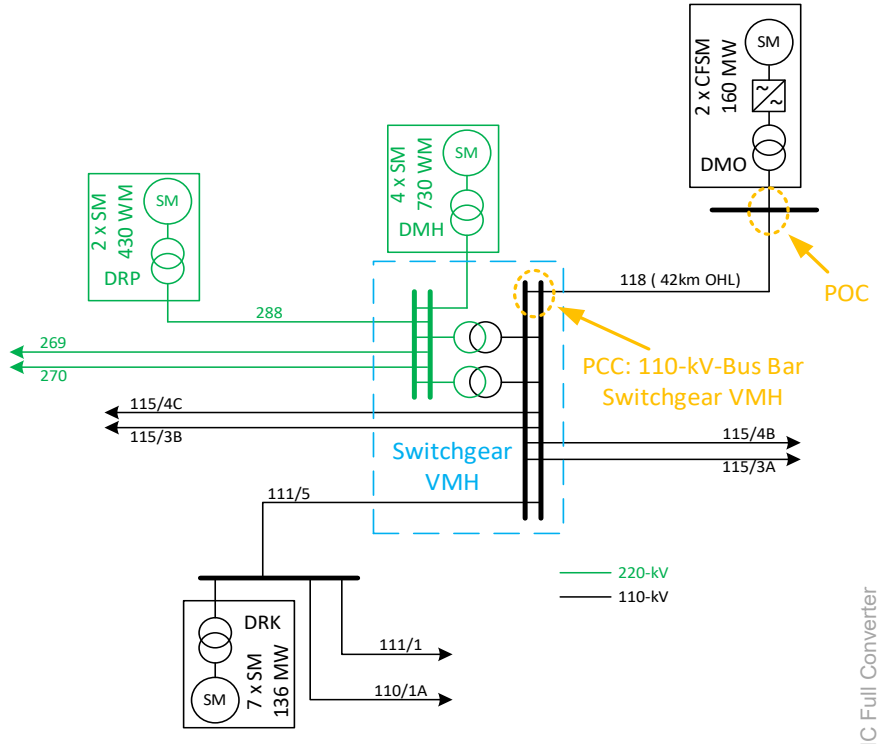
Malta Oberstufe Overhaul Project Variable Speed Operation With MMC Full Converter
Vienna Hydro 2022

Harmonic Performance

Grid requirements

Distortion level set by grid operator
- Half of the IEC 61000-3-6 planning level

Relevant at PCC
- Harmonic studies during project phase
- Measurements during commissioning



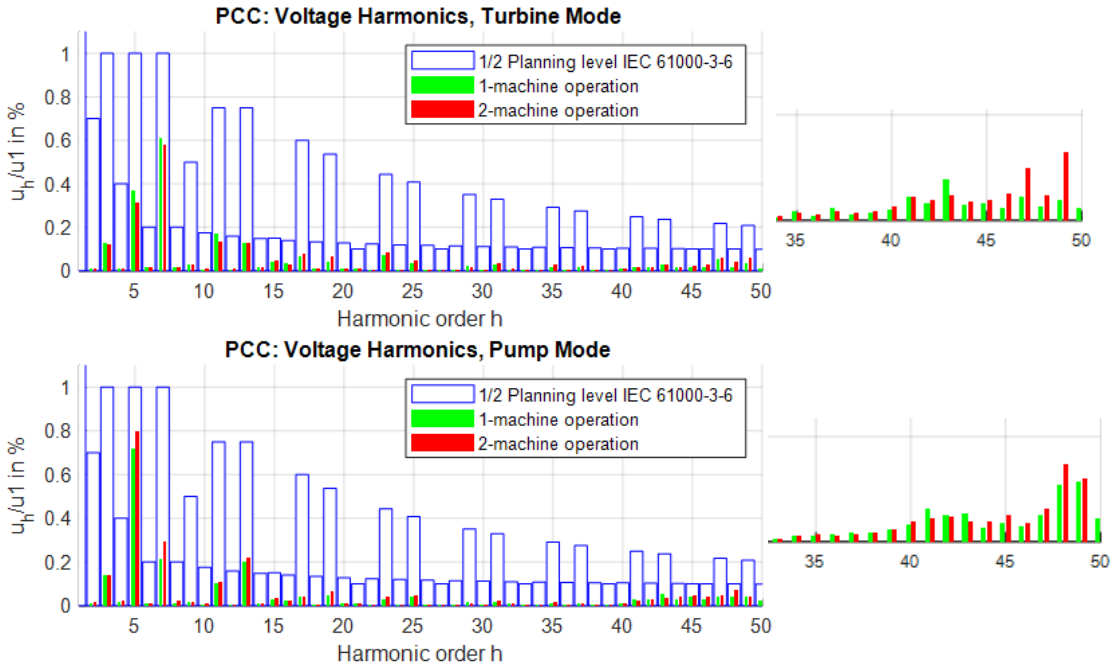
Measurement results

Envelope of several operational points
- Worst Case considerations
- No violations

Little dependency on operational point

Low order harmonics (< 20th) mainly from other sources

System resonance around 43th
- Measurement confirms studies



Malfunction of winding fault protection

Problem

Winding fault protection false tripping
- Stator winding
- Transformer secondary windings

Evaluation of residual voltage at open D
- Voltage exceeds trigger level without fault
- Only in low power operation

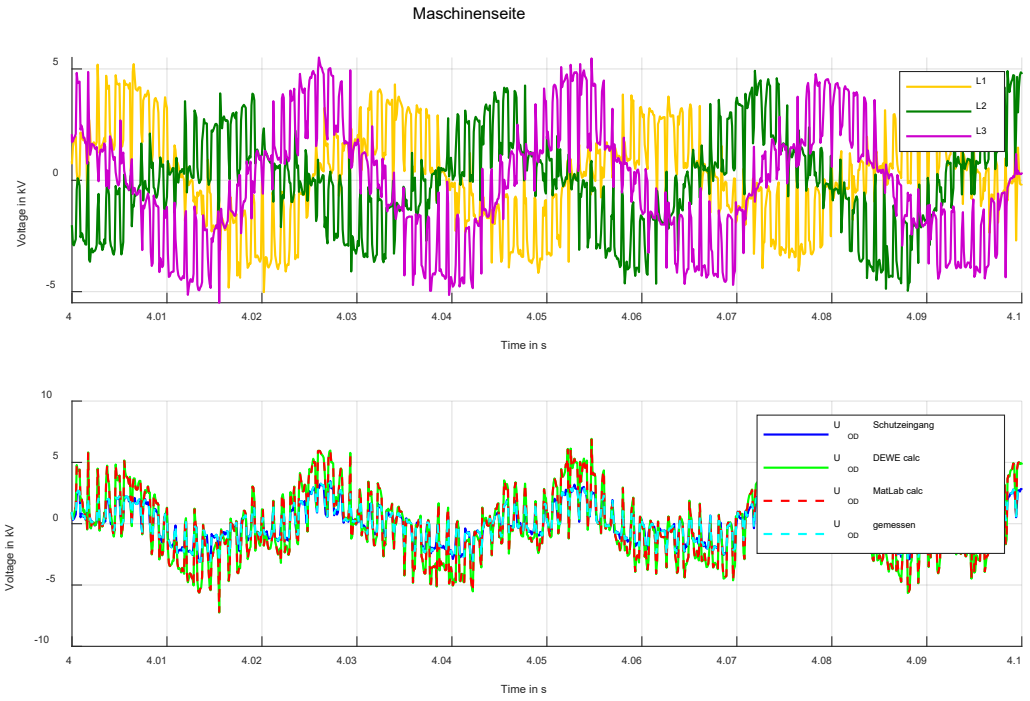
Identified Cause

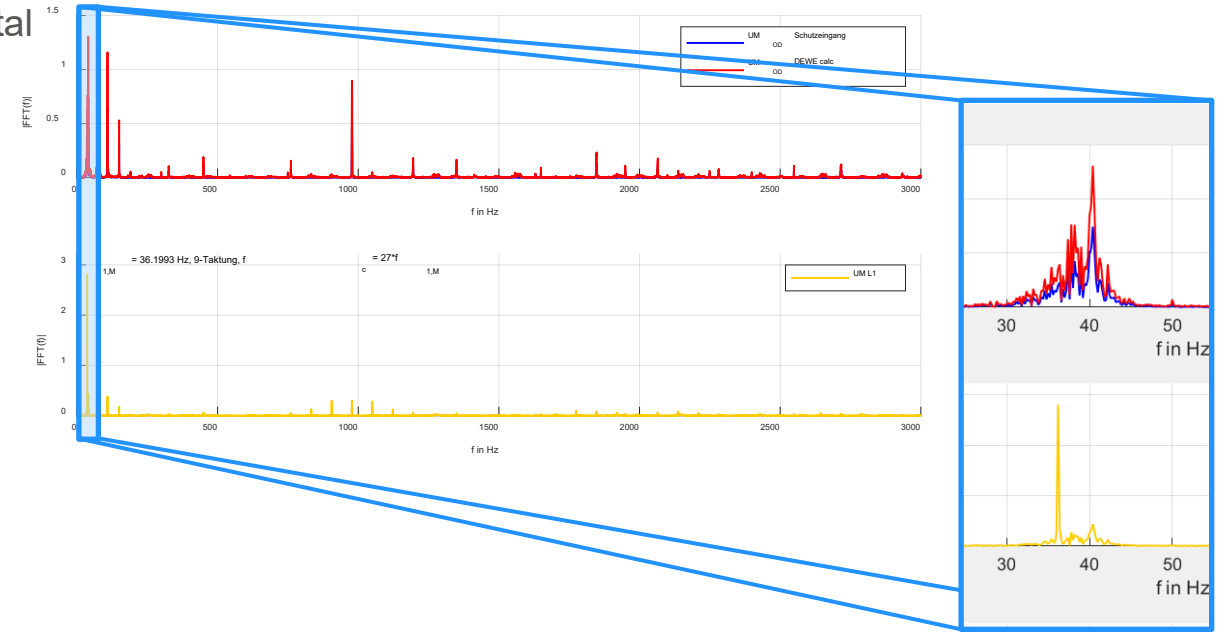
Caused by floating machine side
- Floating DC-Links oscillates close to fundamental
- Voltage transducer measure against grounding
- Oscillation occurs in measured residual voltage

Remedy Action And Lessons Learned

Restriction of low speed operation
- Low power and low head
- Little operational influence

Active winding protection for future projects
- 20 Hz-method





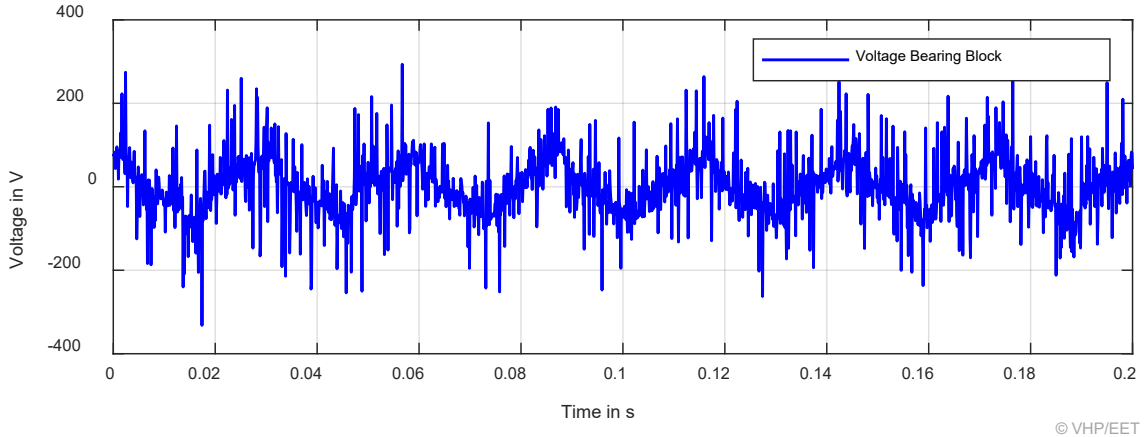
High-frequency Shaft Voltage and bearing currents

Problem

Shaft voltages up to 700 V (peak – peak)

Risk of discharges at insulated bearing
- Bearing insulation
- Oil film

Discharges at sensors



Identified Cause

Common mode voltage Converter
- Caused by discrete output voltage
- Depends on pulsing pattern
- Capacitive coupling

Remedy Action And Lessons Learned

Short circuit path shaft to insulated bearing
- Protection of bearing surface

Additional high frequency grounding
- Reduction of shaft voltage
- RC configuration
- High impedance for low frequencies necessary

Low impedance grounding between generator and converter