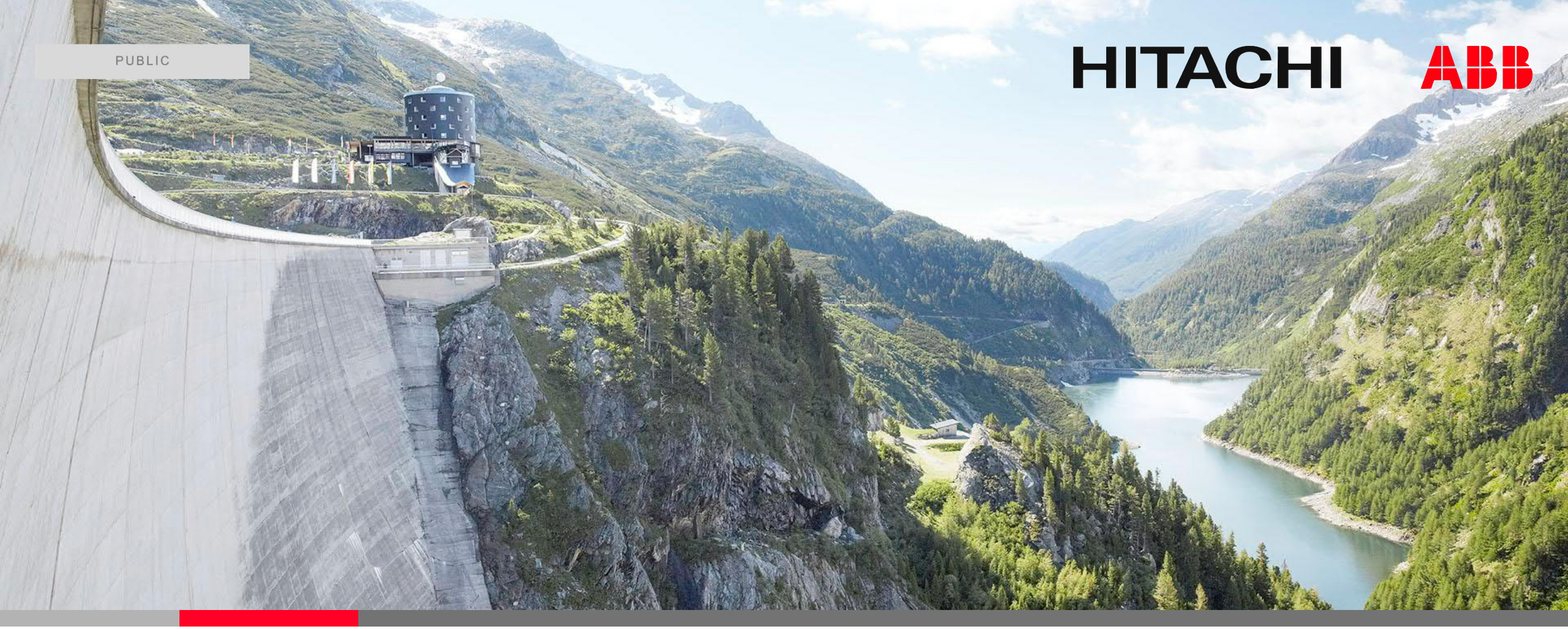

Direct MMC for Converter-Fed Synchronous Machines

System Design Considerations

Michail Vasiladiotis, R&D Team Leader, Grid and Power Quality Solutions

POWERING GOOD FOR SUSTAINABLE ENERGY

2021-05-11

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Agenda

1. Introduction and overview
2. Direct ac/ac modular multilevel converters (MMC)
3. Converter system design aspects
4. Hydro SFC Light
5. Summary

Pumped hydro energy storage

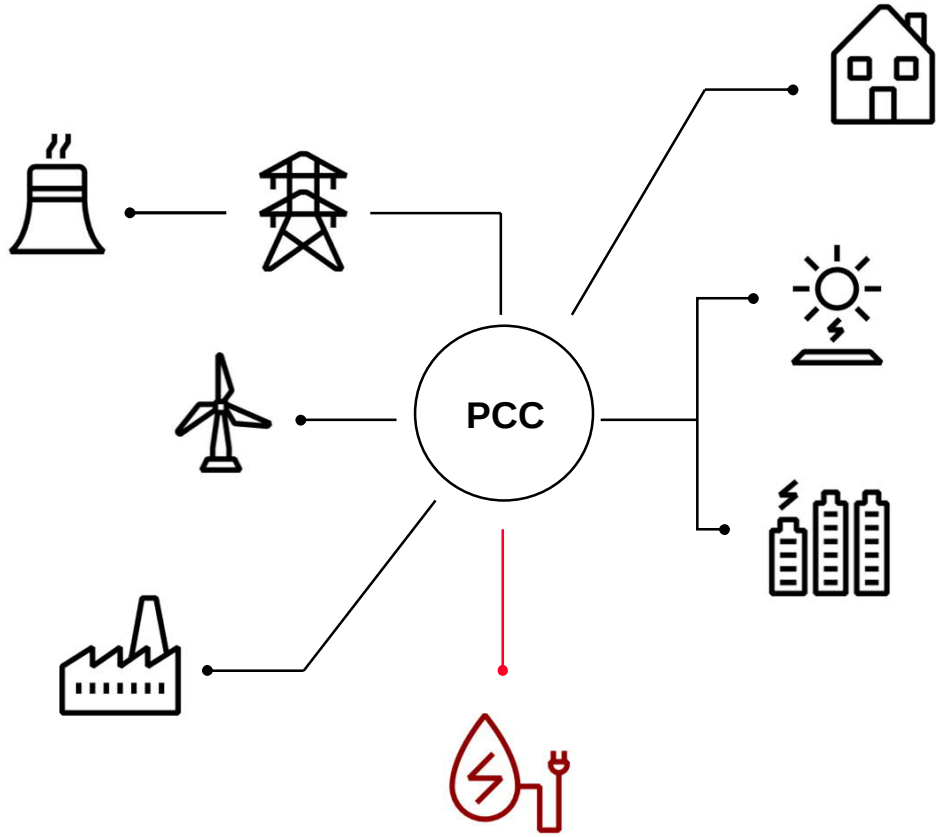
Outlook until 2030

The need for energy storage

- Constant change to distributed power generation
- Vast integration of renewable energy sources

Pumped-storage hydroelectricity

- Storing excess power in form of potential energy
- Reusing during insufficient electrical generation
- 150 GW installed in 2014
  - Expected to be 300-325 GW in 2030[1]



[1]*IRENA, International Renewable Energy Association - Remap, A Renewable Energy Roadmap, Edition 2016, Roadmap for a renewable energy future*

Variable speed solution concepts for pumped hydro storage

Converter fed synchronous machine (CFSM)

Variable speed operation

Higher efficiency at partial loads

Providing ancillary services

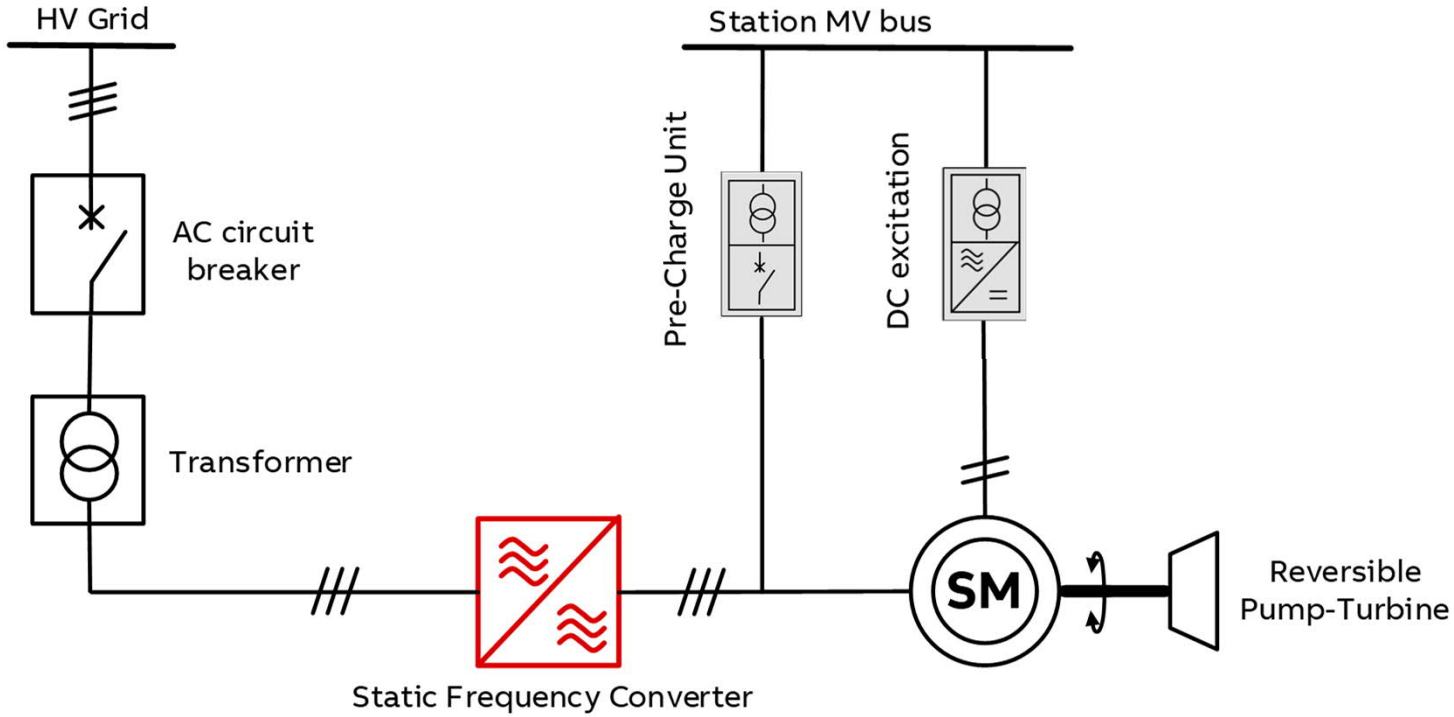
Traditionally through doubly fed induction machine (DFIM)

CFSM needs fully rated converter

Recent advancements in high power electronics and topologies have made this possible

First CFSM operating worldwide in Grimsel

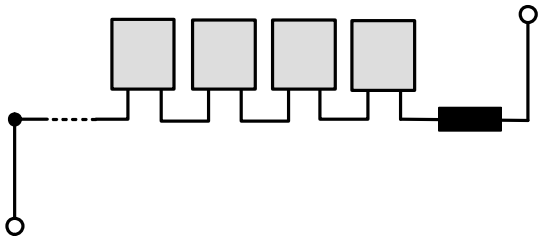
Using ANPC and machine-side transformer



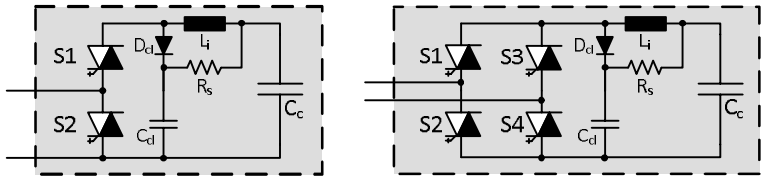
Modular Multilevel Converter: What is it?

Elementary building blocks

Converter phase-leg or branch

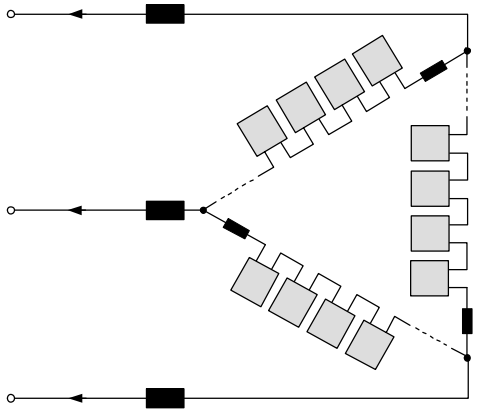


Cell (module, sub-module) implementations

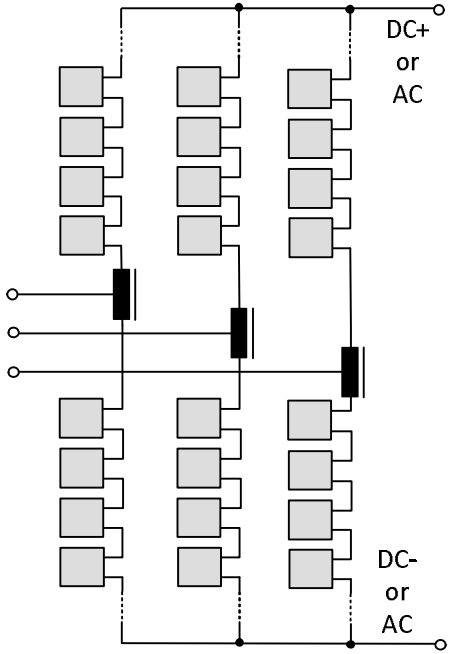


Unipolar cell | Bipolar cell

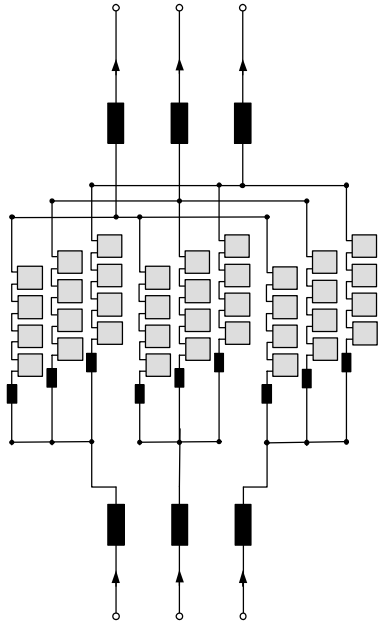
Some members of the Medium Voltage MMC family



STATCOM, Flicker



Rail, MVDC, Energy Storage



Pumped Hydro, Grid Interties

New static frequency conversion concepts

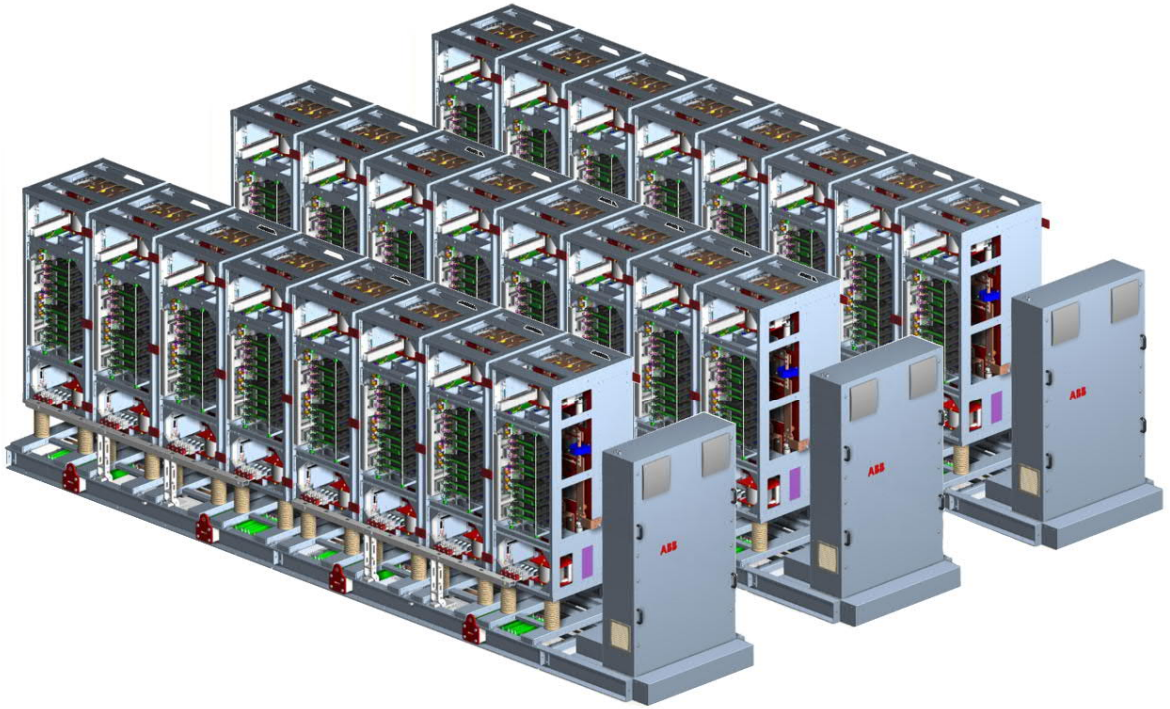
Modular Multilevel Converter advantages and challenges

MMC advantages

– Voltage and power scalability
– High system efficiency
  • High loss penalization
– High number of cells (HVDC MMC case)
  • Control and harmonic performance
– Redundancy

MMC challenges

– Low cell numbers (MV MMC case)
– Minimization of switching frequency desired
  • Control and harmonic performance become an issue
– Low frequency capacitor voltage ripples

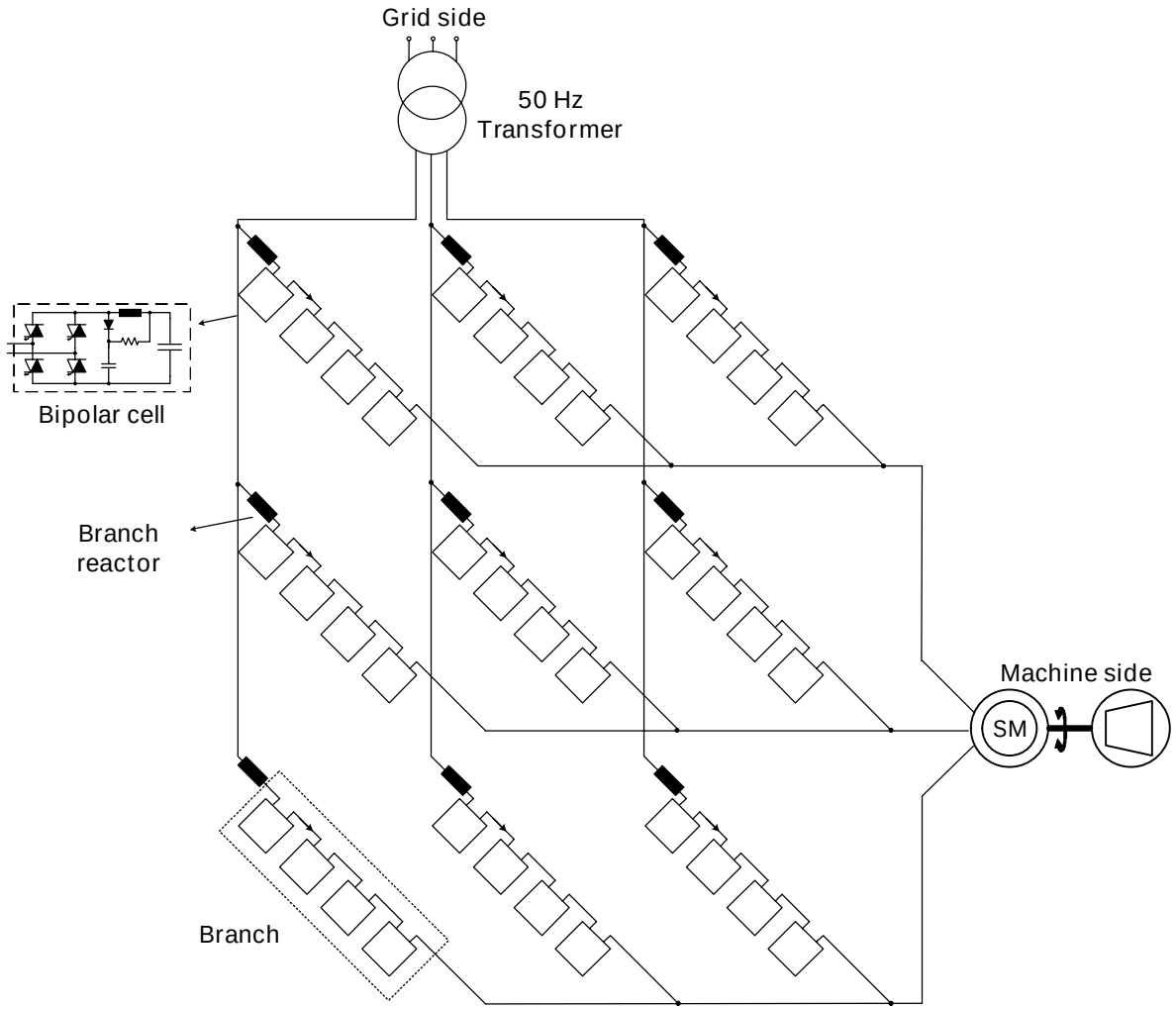


Direct AC/AC Modular Multilevel Converters (MMC)

Features

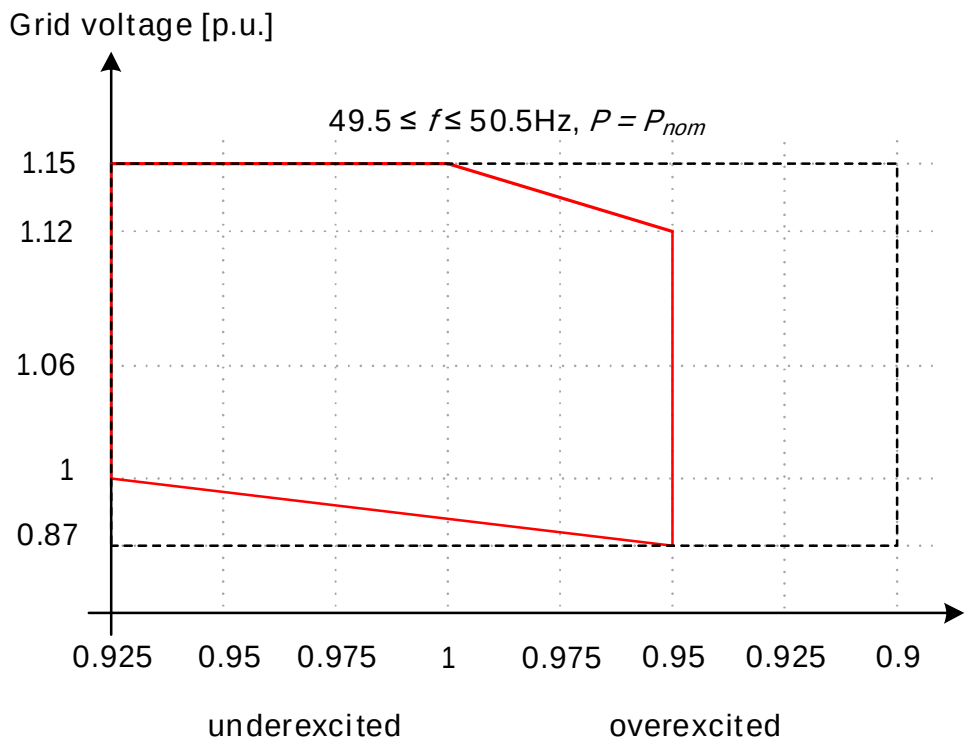
- Suitable for lower machine frequencies
  - Challenges with synchronous operation
- Nine phase-legs, needs bipolar cells
- During faults the whole current capability can be used towards one side → more than 1 p.u. current
- No transformer needed on the machine side
- Contributions to grid power quality
  - Synthetic inertia can be provided
  - Voltage support through Q-injection

In the following slides an example case of 75MW, 30Hz machine nominal frequency is considered

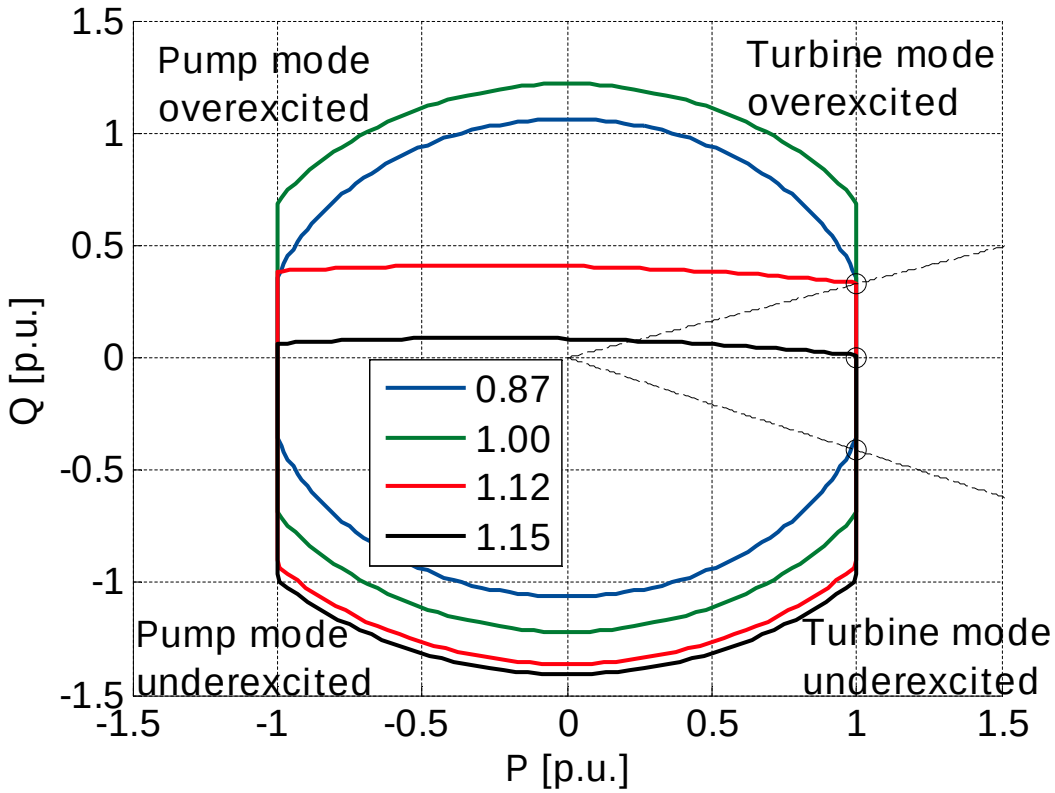


Active vs. reactive power capability

Example of grid code requirements



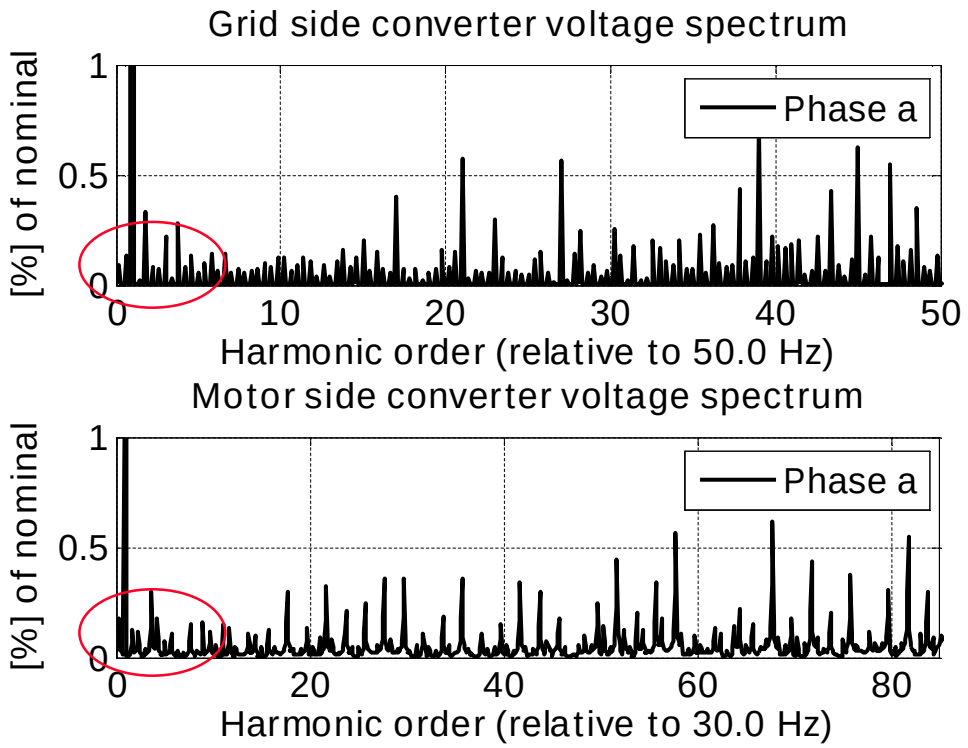
Grid-side PQ diagram for different PCC voltages



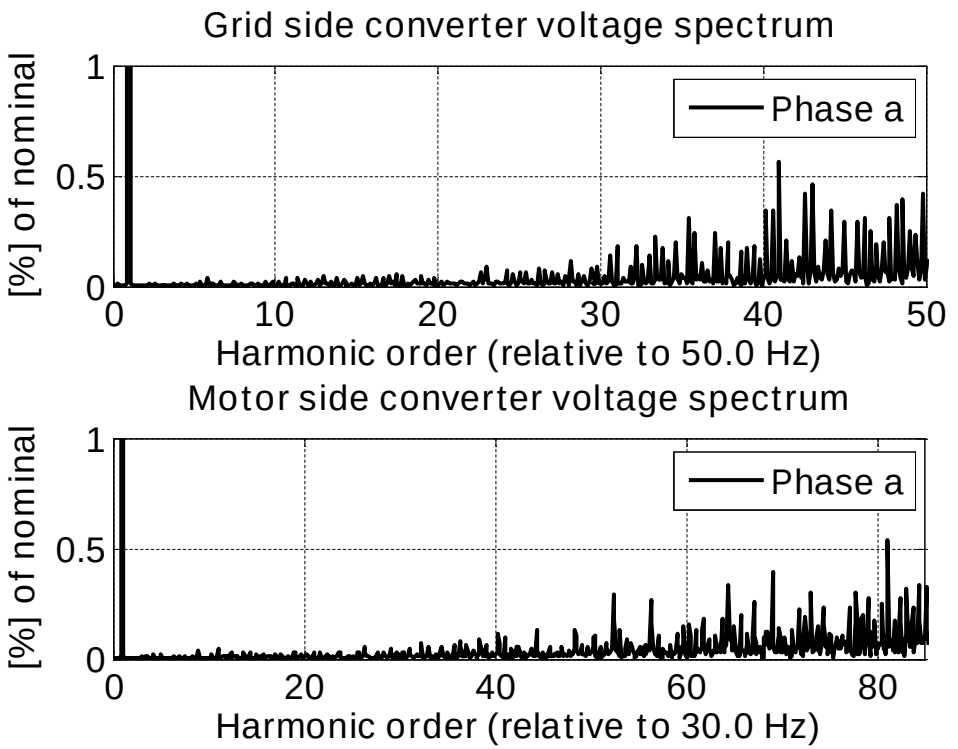
M. Vasiladiotis et al., 'IGCT-based direct ac/ac modular multilevel converters for pumped hydro storage plants,' in Proc. ECCE 2018

Modulation and harmonics

Phase-shifted carrier PWM



Virtual flux error compensation



In operation at low cell numbers and switching frequency, PSC-PWM does not offer acceptable performance

M. Vasiladiotis et al., 'IGCT-based direct ac/ac modular multilevel converters for pumped hydro storage plants,' in Proc. ECCE 2018

Failure handling and redundancy

Cell bypass after loss of cell

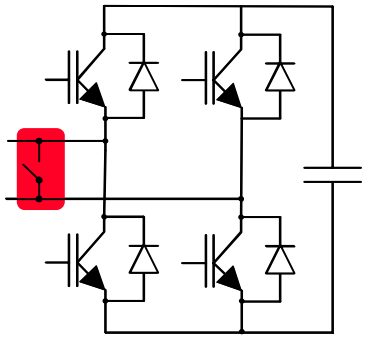
– Reliable bypass mechanism has to avoid overcharging of the capacitor:

  • Semiconductor with module housing (state of the art for IGBT) has to be shorted at the AC terminals.

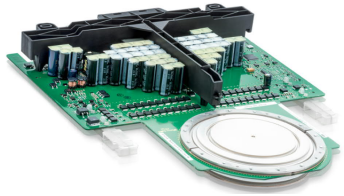
• Diodes in a press pack device will contribute to the short circuit path.

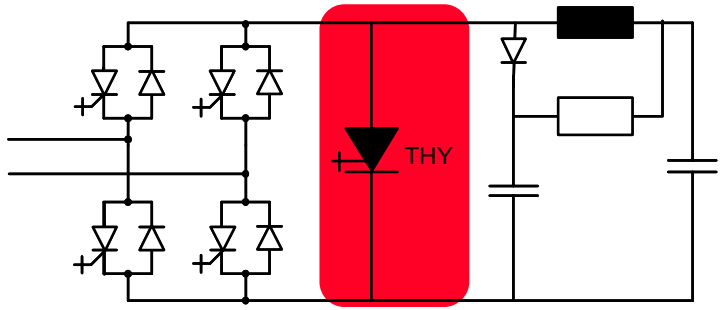
  → Shorting the capacitor with a thyristor is sufficient!

IGBT cell



IGCT cell

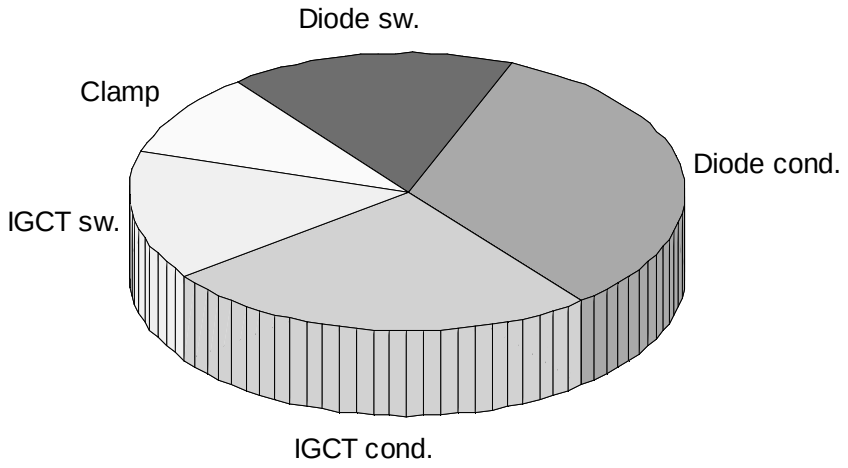




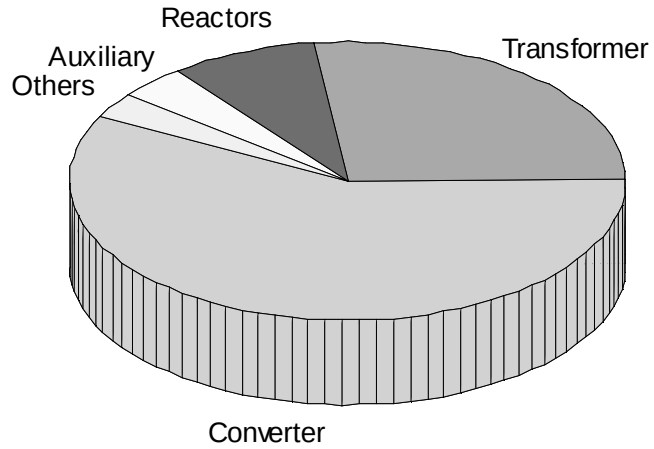
D. Weiss et al., 'IGCT-based modular multilevel converter for an AC-AC railway power supply,' in Proc. PCIM 2017

Converter and system losses

Converter cell loss breakdown



System loss breakdown

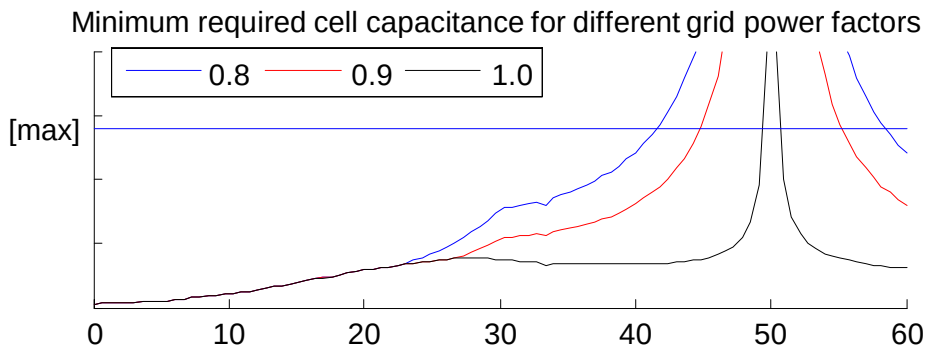


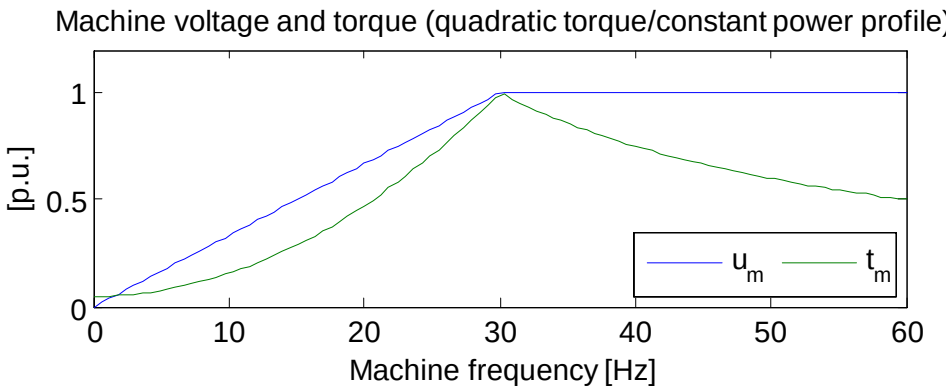
System efficiency can exceed 98.5%

M. Vasiladiotis et al., 'IGCT-based direct ac/ac modular multilevel converters for pumped hydro storage plants,' in Proc. ECCE 2018

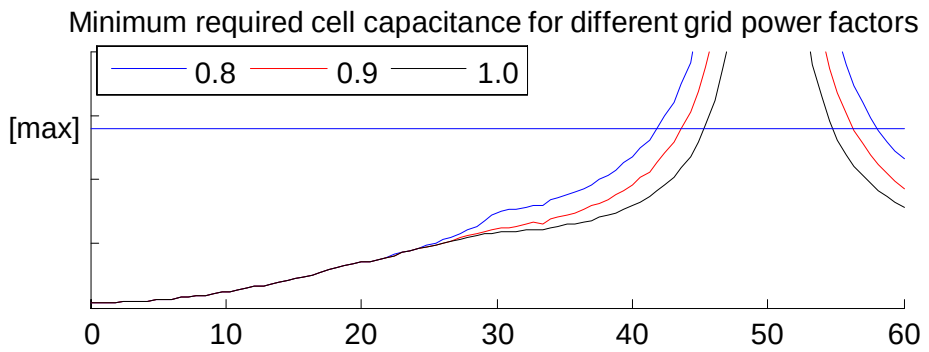
Capacitance dimensioning consideration examples

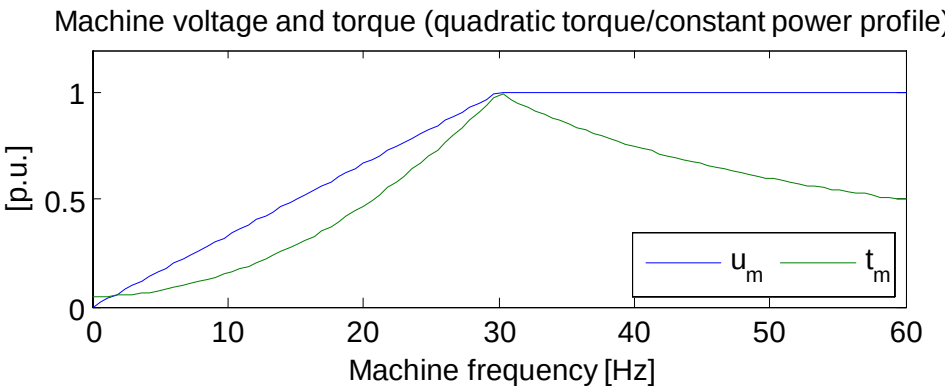
Input/output voltage ratio: 1.02 , set ripple +-10%





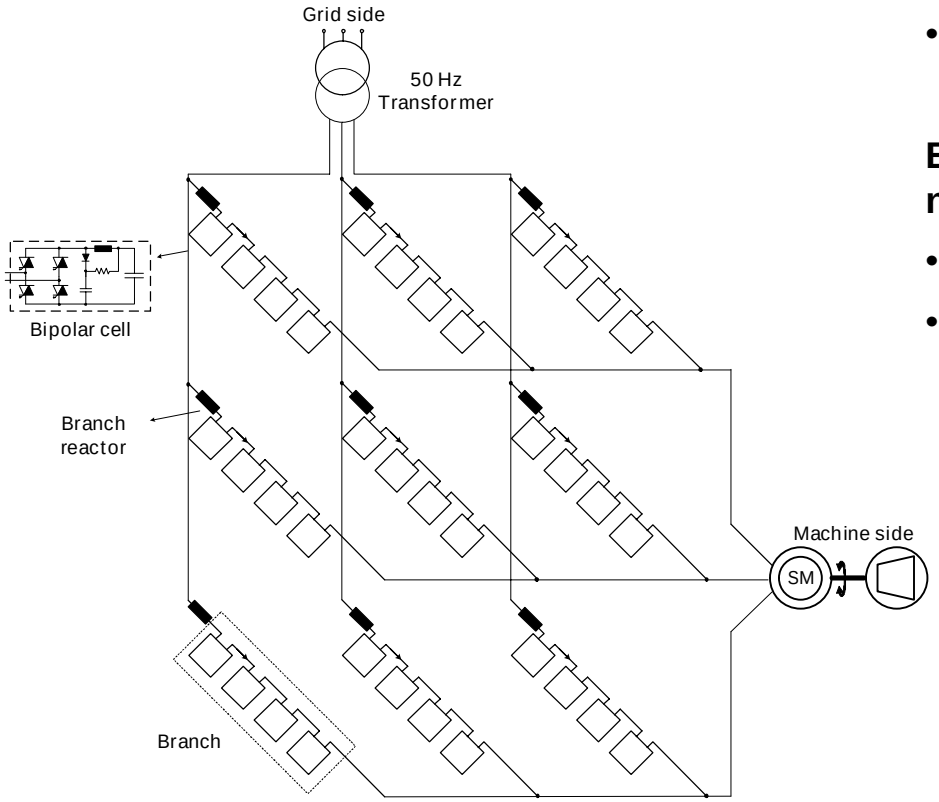
Input/output voltage ratio: 1.21 , set ripple +-10%





Influencing factors: Machine to grid voltage and frequency ratio, grid power factor

Reactive current capability during grid faults



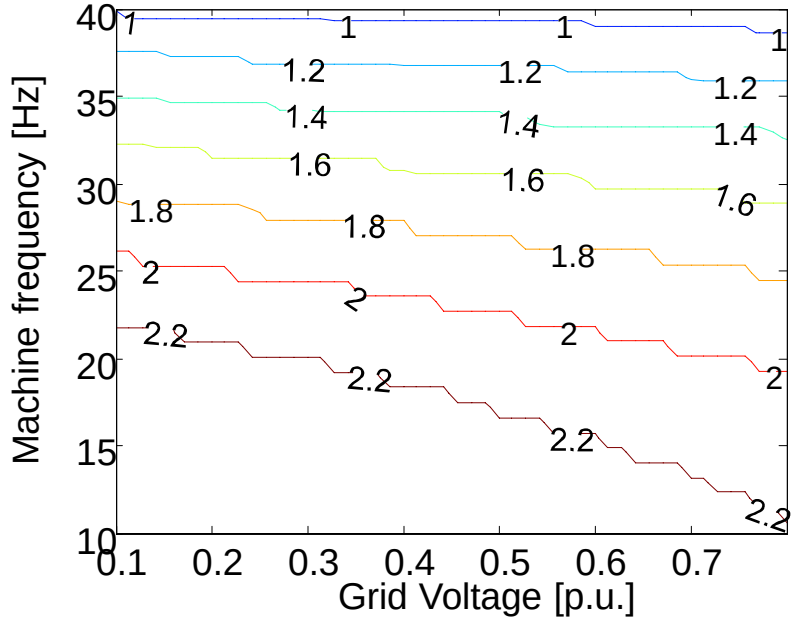
Constraints

- Maximum phase-leg current
- Maximum voltage variation
- Overmodulation

Example (control transient effects not considered)

- Nominal voltage ratio k = 1.15
- Maximum voltage ripple +12.5%

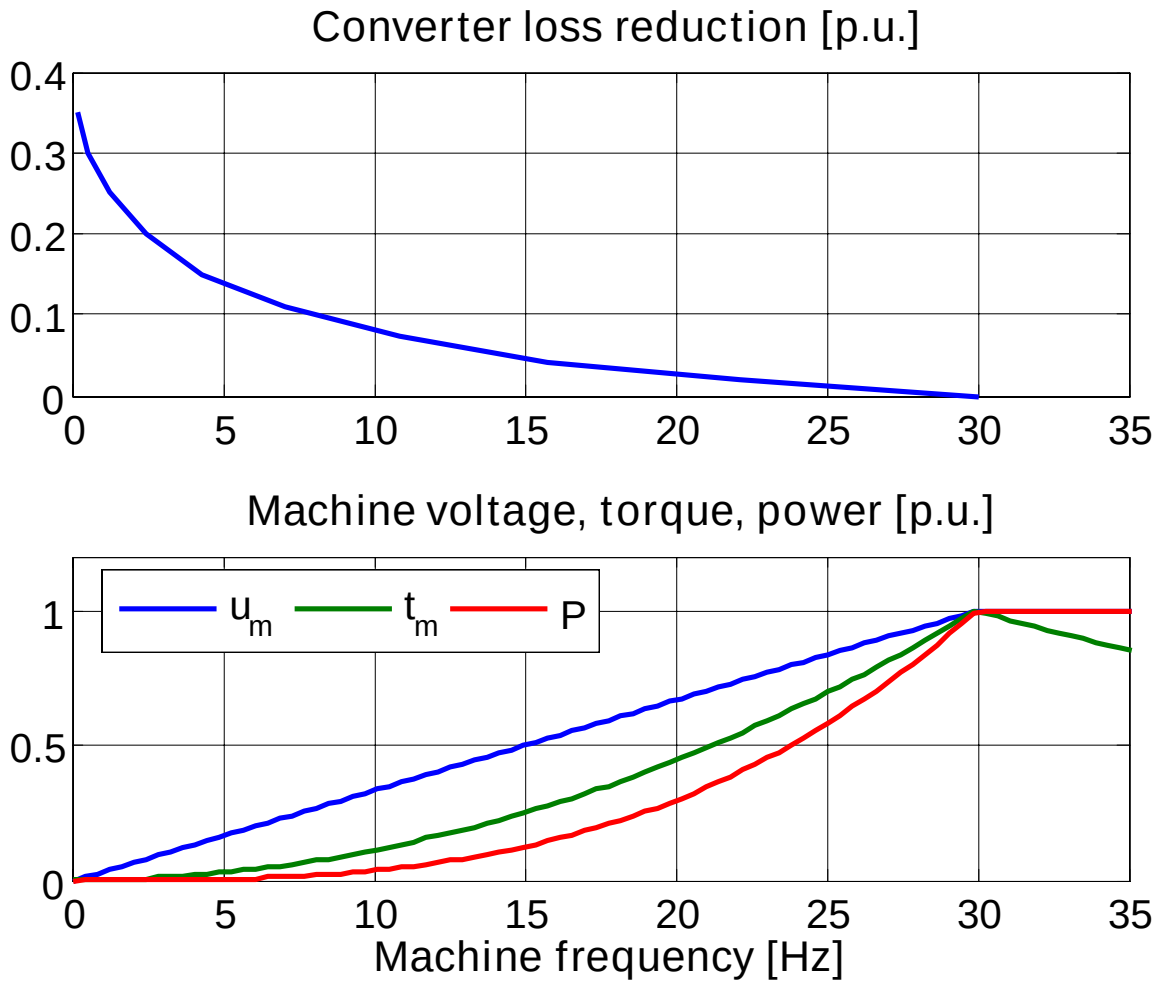
Maximum inductive reactive current capability [p.u.]



Increasing converter efficiency at partial speed/load

Cell voltage reduction

- ω ~ Um (synchronous machine)
- Big voltage reserve at lower speed
- Switching loss dependency on cell voltage
- No overmodulation



M. Vasiladiotis et al., 'IGCT-based direct ac/ac modular multilevel converters for pumped hydro storage plants,' in Proc. ECCE 2018

Making it happen: Hydro SFC Light product development

Customer projects

- **Project ‘Malta’ (Verbund - Austria)**
  - **Awarded and put in operation**

- One other project awarded
- Projects in sales pipeline

First company to put in operation a direct 3ph/3ph MMC worldwide!

Direct MMC for converter-fed synchronous machines

Summary

Direct MMCs for variable speed pumped hydro storage plants

- Advanced high-power electronics devices and topologies enable fully rated converters
- High system efficiencies are advantageous → Loss penalization schemes
- More than 1 p.u. grid current for Fault Ride Through under certain conditions
- Modulation and control challenges exist
- New design rules and concepts for power converters

Direct MMC using RC-IGCTs

- Low conduction losses
  - Low switching frequencies
- Presspack device
  - Safety and robustness, no explosion during failure
- Well-established technology, optimized for this application

Acknowledgements

- R&D
  - A. Faulstich, A. Christe, B. Buchmann, D. Wu, S. Herold, M. Kläusler, G. Beanato, J. Steinke
  - MMC platform HW team

- Engineering/ Project Execution
  - P. Steinmann, C. Häderli, Shanmugam V., B. Epple, J. Smeu, A. Alibegovic

- Product management/ Sales
  - T. Thurnherr, S. Aubert

- And many more involved…

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