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USAGE AND ADVANTAGE OF FAST SWITCHING MV CONVERTERS FOR GRID EMULATION

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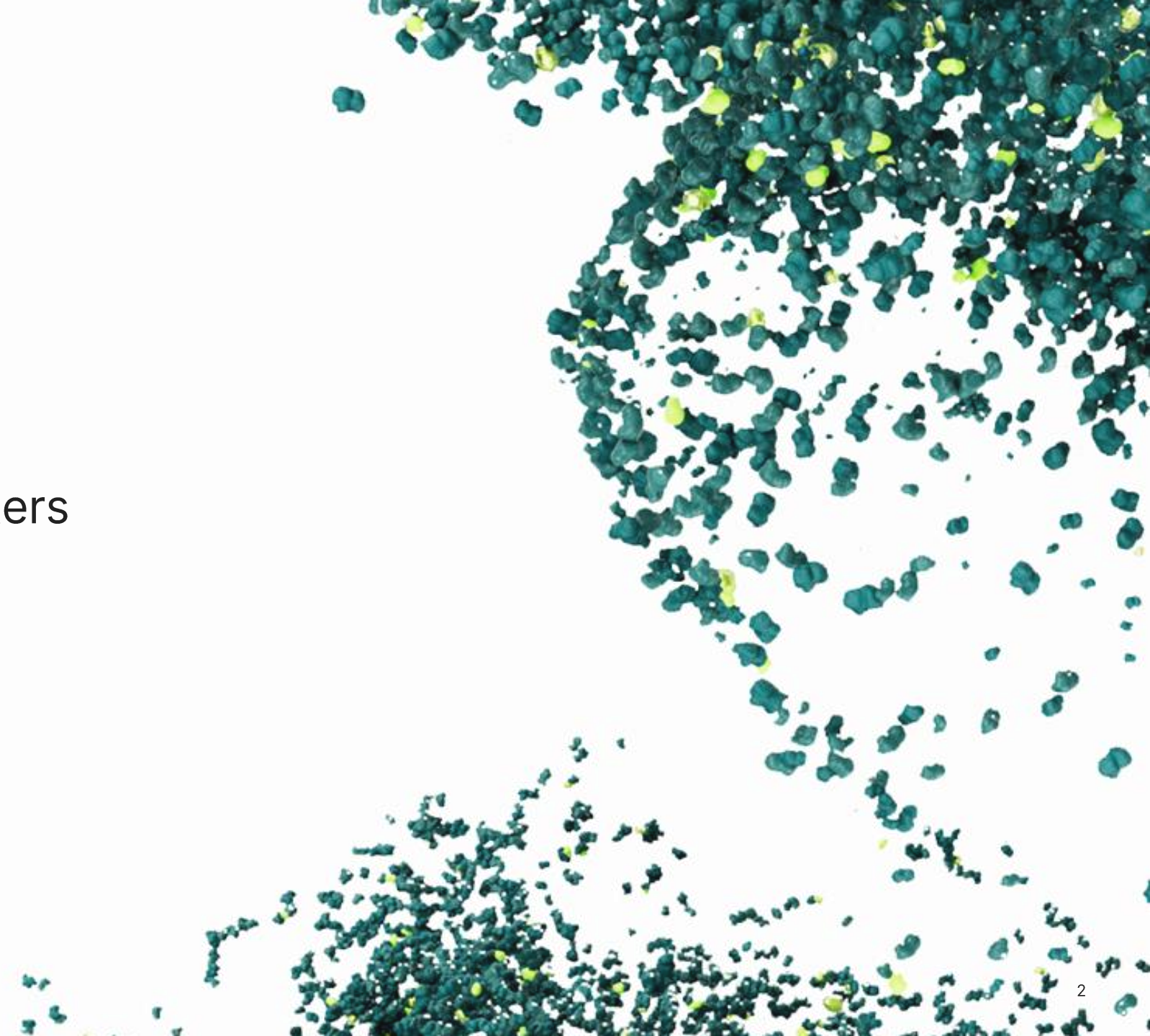
GE Vernova, Power Conversion
7th int. Workshop on Grid Simulator Testing of Energy Systems and Wind Turbine Drivetrains
2nd Oct. 2024, Bremen, Germany

Agenda

- Company presentation
- Core products
- Grid emulation
- Fast switching MV converters
- Summary



COMPANY PRESENTATION

For the new era of energy... a new company with full focus on the energy transition

GE VERNOVA

75K+
Employees globally in

100+
Countries

POWER
Gas Power, Hydro Power, Nuclear, Steam Power

WIND
LM Wind Power, Onshore Wind, Offshore Wind

ELECTRIFICATION
Grid Solutions, Power Conversion, Solar & Storage Solutions, Electrification Software

ACCELERATORS
Advanced Research, Consulting Services, Financial Services

Power Conversion worldwide – a global network

Serving mission critical sectors, driving the electric transformation of the world's energy infrastructure

GE VERNOVA

Power

- Power Generation
- Power Supply & Primary Distribution
- Power Quality

Oil & Gas

- Upstream
- Midstream
- Downstream
- LNG

Industry

- Steel & Metals
- Mining & Hydrometallurgy
- Hydro Pump storage
- Rail
- Research & Test
- H2 & Microgrids

Marine

- Naval
- Offshore Industries
- Transportation
- Ports

Services

CORE PRODUCTS

OUR CORE PRODUCTS

GE VERNOVA

POWER ELECTRONICS

- High power density
- High reliability and availability
- Power scalability

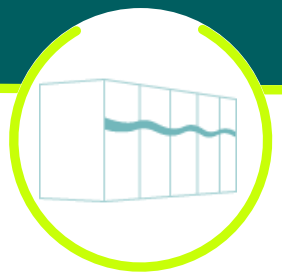
CONTROL & AUTOMATION

- Innovative design and supply of automation and control solutions
- High efficiency and enhanced asset availability through remote monitoring and data analytics

Low Voltage Drives

Modular and compact low voltage drives for reliable performance from 0.2 to 4MW at 270 up to 900V

- ✓ LV8
- ✓ LV7
- ✓ LV3



Medium Voltage Drives

Reliable, high performance medium voltage variable speed drives from 3 to 100+ MW at up to 33kV

- ✓ MV73XX
- ✓ MV76XX
- ✓ MM7

Special Voltage Drives

Air cooled excitation & startup converters, LCIs, rectifier, cyclo converters and liquid cooled thyristor-based units

- ✓ MiniSemi
- ✓ PowerSemi
- ✓ SemiPol
- ✓ PAXX
- ✓ PWXX

Control & Automation

- ✓ High Performance Controller (HPCi)
- ✓ Power Electronic Controller (PECe)
- ✓ Asset Management, analytics and operator Interface

Digital

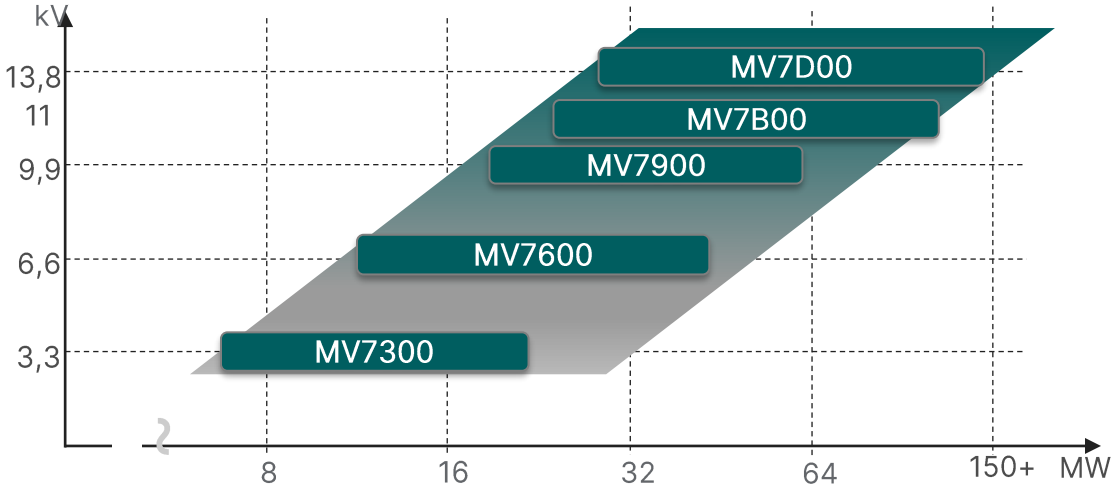
Power Conversion`s Asset Performance Management (APM)

- ✓ Rotating machine analytics
- ✓ Drive Analytics

Digital Metals

MV7 SERIES

Proven MV7 medium-voltage drive (link) solution on various industry applications



Full range for customer needs

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MV7 is a drive technology delivering efficient and flexible control of electric power to all driven equipment

Oil & Gas
Electrical LNG
Electric steam cracker
Gas transportation
High-speed
CO_2 injection
Booster
LNG carriers
Starter / Helper
Subsea

Marine
Cruise ships
Offshore drilling vessels
Research vessels
Mega-yachts
Merchant vessels
Navy support vessels

Power & Industry
DSVC, Statcom
Hot and cold rolling mills
Mine winders, SAG mills
Water pump and transport
Wind test benches
Pumping storage
Boiler feed pumps
Rail SFCs, power supplies

HIGH PERFORMANCE

High power density solution for various motor types (induction, synchronous, high-speed & permanent magnet) up to 100MW

RELIABILITY

Extensive track record with more than 19 GW installed since 2005 allowing for more than 80 million hours of operation in various applications

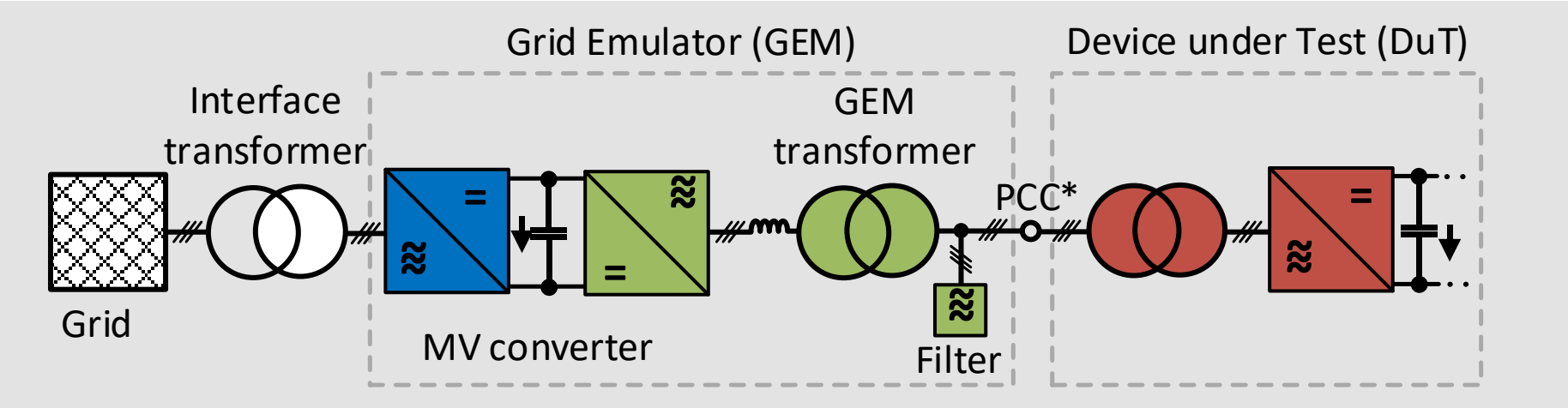
MODULARITY

MV7 drive provides a flexible, modular approach that uses common building blocks to achieve a customized solution

GRID EMULATION

Grid Emulation

- Use of MV converters with comparatively low switching frequency
- Devices under test up to appr. 15 MW
- Typical and new requirements for grid emulators (GEM):
  - Frequency range for cont. operation 45 – 65 Hz
  - Voltage range for continuous operation 90 – 110%
  - Voltage range for dynamic operation 0 - 150 %
  - Emulation of short-circuit ratio > 3
  - Total harmonic voltage distortion THD_V < 2%
  - Harmonic injection with likely reaching up to 100th order



General setup of a grid emulator system

Grid Emulation

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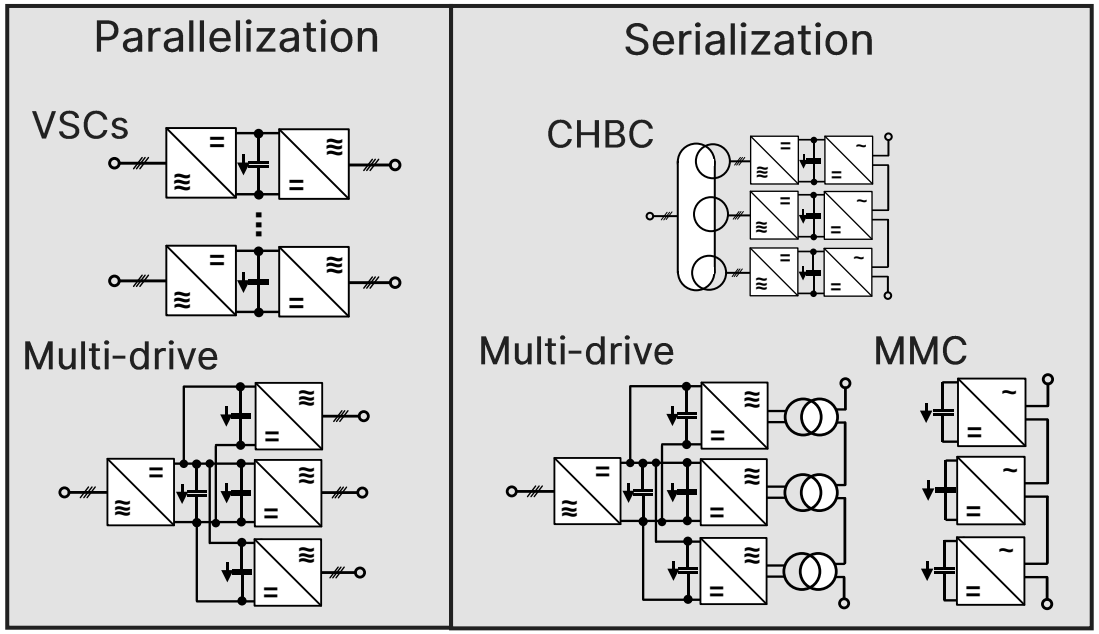
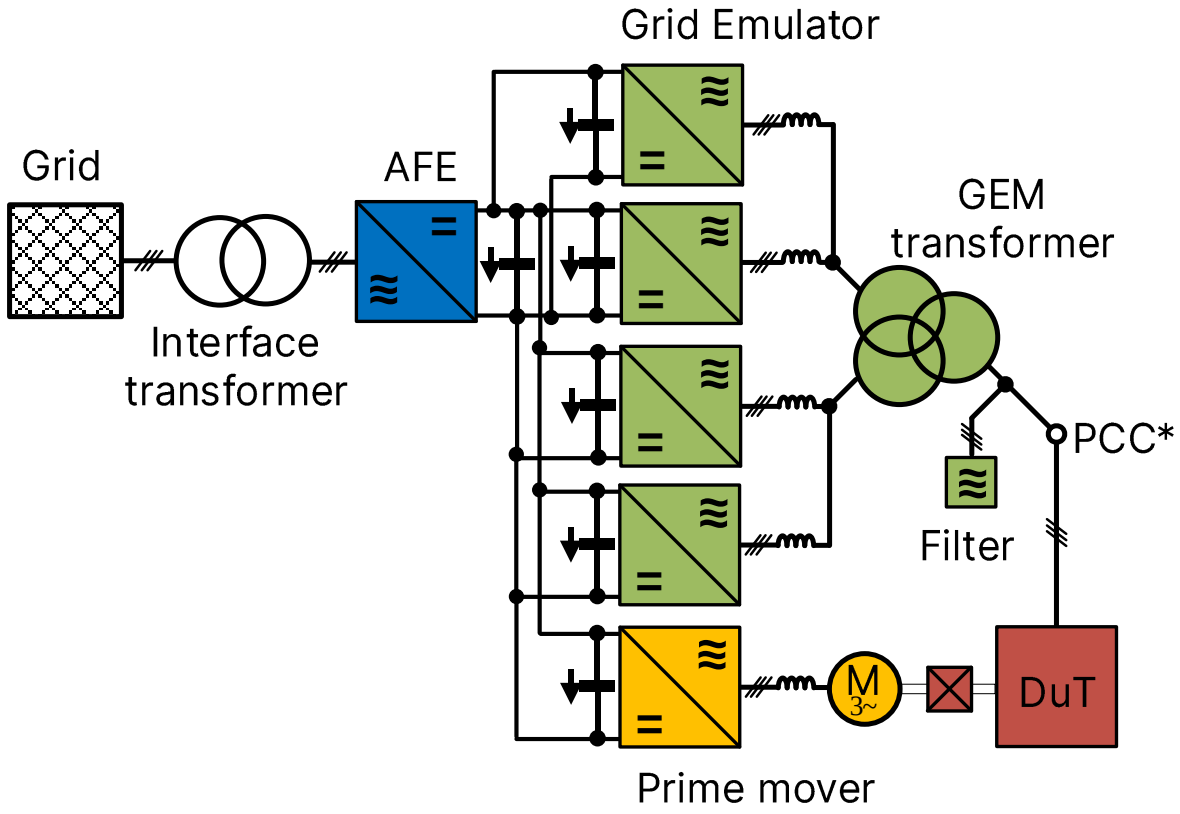
Configuration of grid emulator converters

- Parallelization and serialization concepts
- Derating of grid-emulator power



Converter configurations for grid emulation



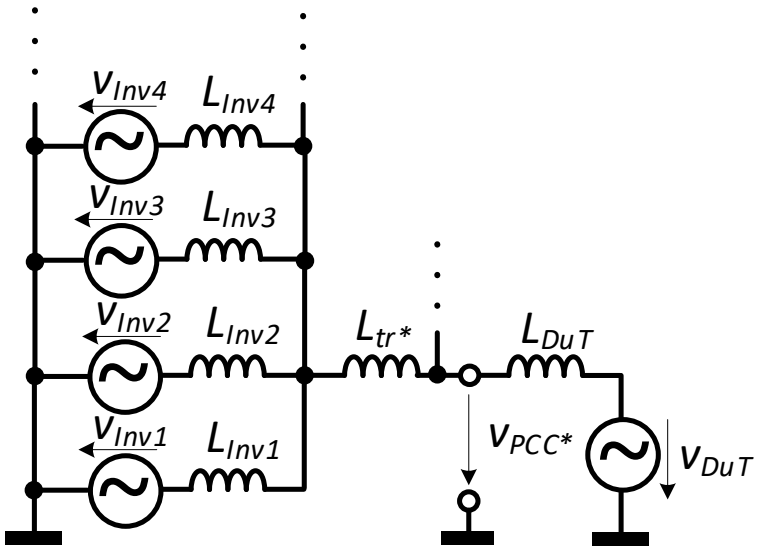
Grid emulator based on multi-drive converter system, cp. [1]

[1] C. Saniter and J. Janning, Test Bench for Grid Code Simulations for Multi-MW Wind Turbines, Design and Control, in IEEE Trans. on Power Electr., vol. 23, no. 4, pp. 1707 - 1715, July 2008

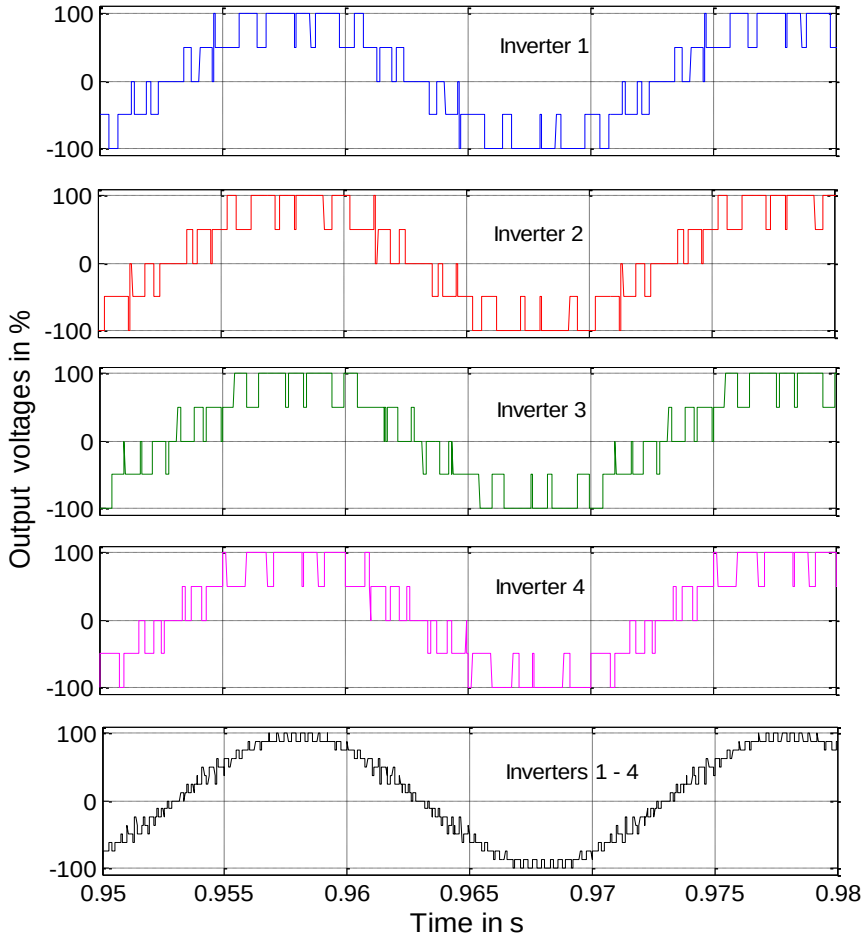
Grid Emulation

Paralleling of medium-voltage converters

- Pulse-interleaved pulse width modulation (PWM)
- Interposing (transformer) impedances
- Additional voltage levels at the GEM output



Equivalent circuit for parallelization of inverters



Modulated output voltage of four interleaved inverters (f_{car}=750 Hz)

FAST SWITCHING MV CONVERTERS

Fast Switching MV Converters

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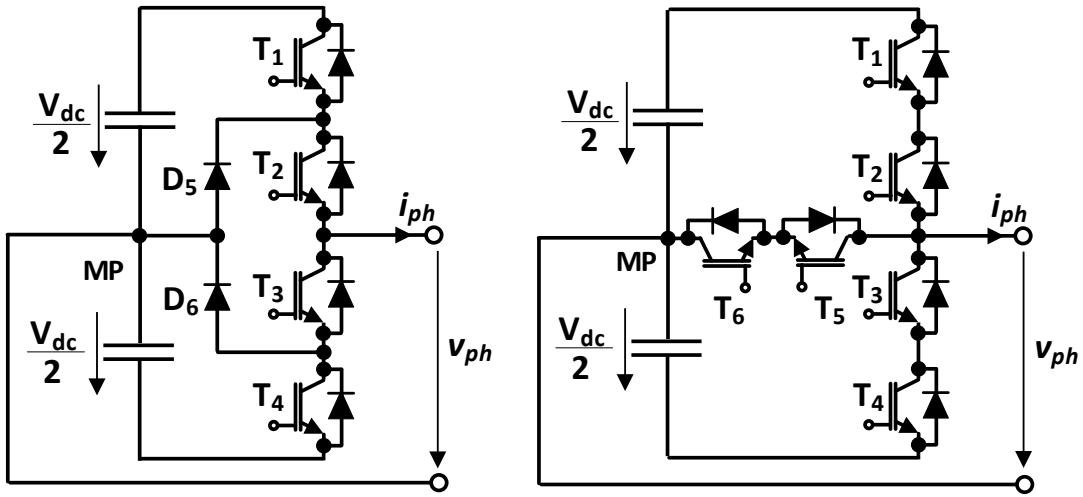
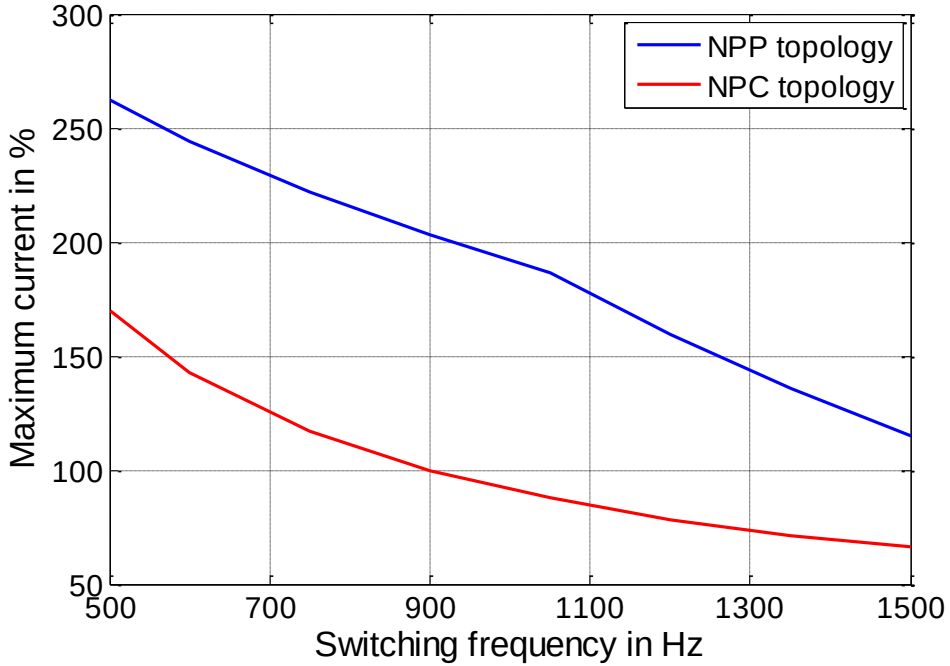
Topologies for MV converters

- Neutral Point Clamped (NPC)
- Neutral Point Piloted (NPP)
- NPP advantageous for higher switching frequency



3L NPC inverter (left) and NPP inverter (right)



Example calculation of maximum current against max. switching frequency for same semiconductors (M=0.8, V_{dc}=5kV, PF=1)

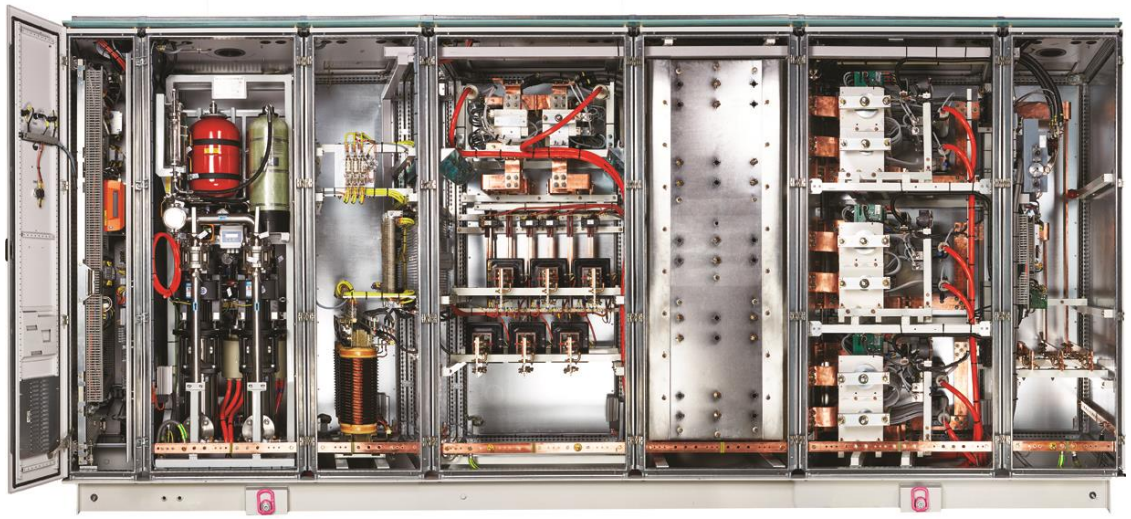
Source: M. Geske, P. Sadowski, M. Janssen, J. Serra Rivas, H.S. Hildebrand: The neutral-point piloted inverter topology applied to grid emulation, ECCE Conf., Darmstadt, Germany, Sep. 2024

Fast Switching MV Converters

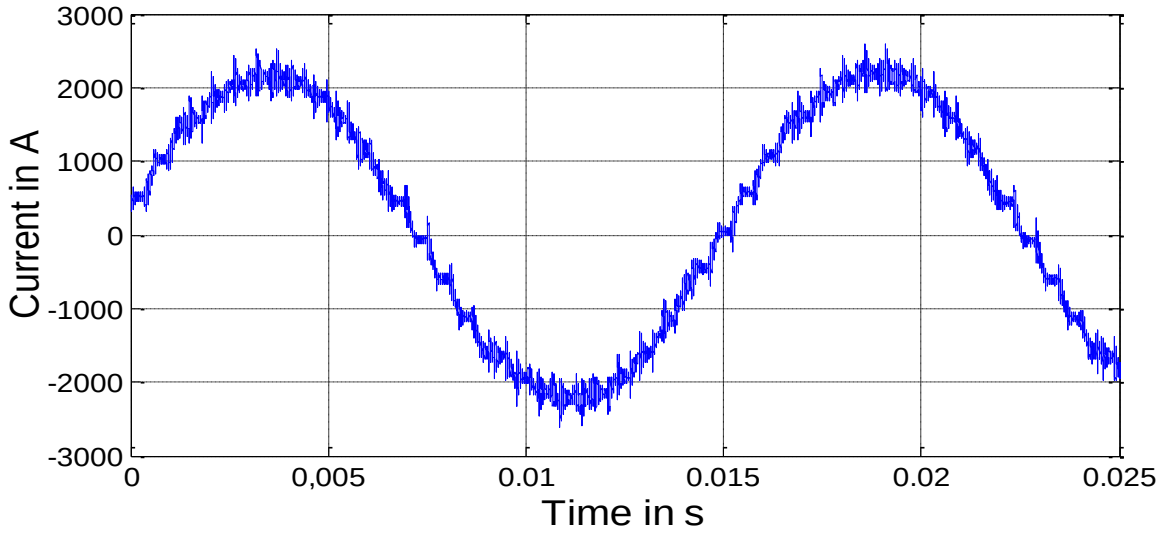
MV7 drive converter

- Three-level NPP topology
- Press-pack IGBTs
- 3.3 kV_{ac} with up to 17 MVA

MV7 power stack



MV7 converter type MV7315-3L (NPP topology)

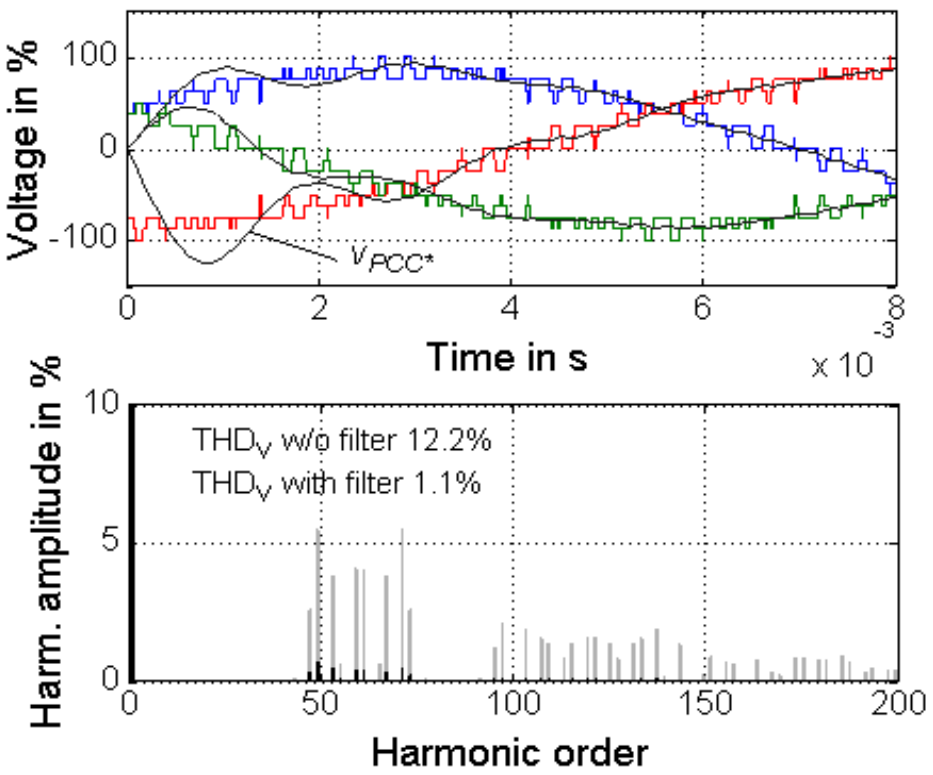


Output current of MV7315-3L (f_{car}=1755 Hz, 65 Hz)

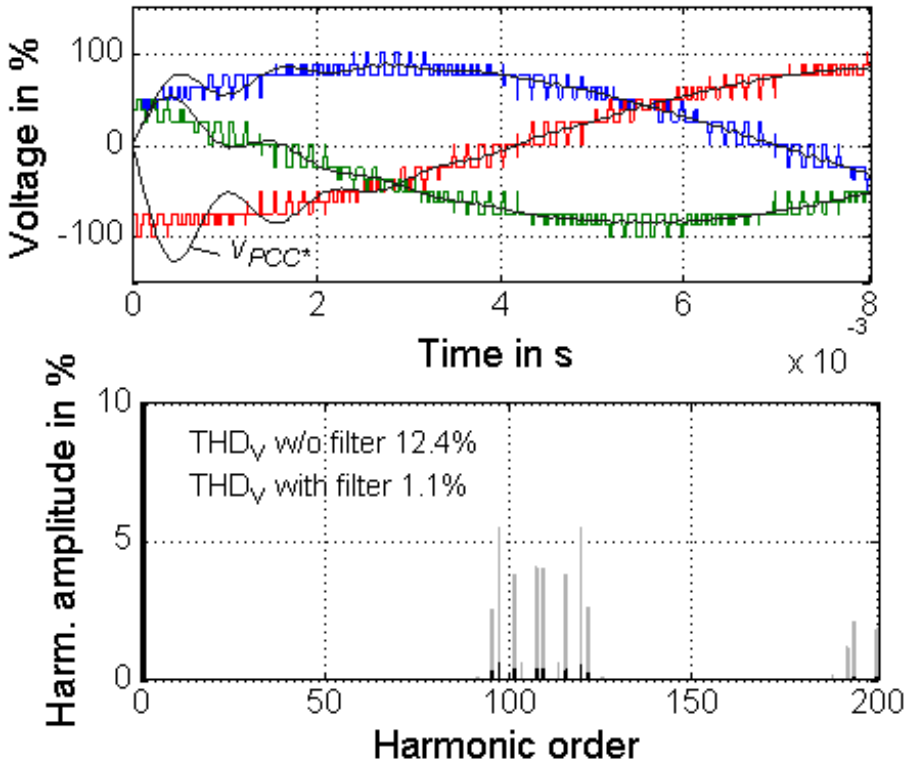
Source: M. Geske, P. Sadowski, M. Janssen, J. Serra Rivas, H.S. Hildebrand: The neutral-point piloted inverter topology applied to grid emulation, ECCE Conf., Darmstadt, Germany, Sep. 2024

Fast Switching MV Converters

Advantage of high switching frequency: Smaller filter rating and higher dynamics



Simulated output voltages (top), harmonic rms amplitudes (bottom) for f_{car}= 900 Hz ($f_{cut\text{-}off}$ =660 Hz, $f_{N(PCC^*)}$=60 Hz, 4 inv.)



Simulated output voltages (top), harmonic rms amplitudes (bottom) for f_{car}= 1620 Hz ($f_{cut\text{-}off}$ = 1200 Hz, $f_{N(PCC^*)}$= 60 Hz, 4 inv.)

Source: M. Geske, P. Sadowski, M. Janssen, J. Serra Rivas, H.S. Hildebrand: The neutral-point piloted inverter topology applied to grid emulation, ECCE Conf., Darmstadt, Germany, Sep. 2024

Fast Switching MV Converters

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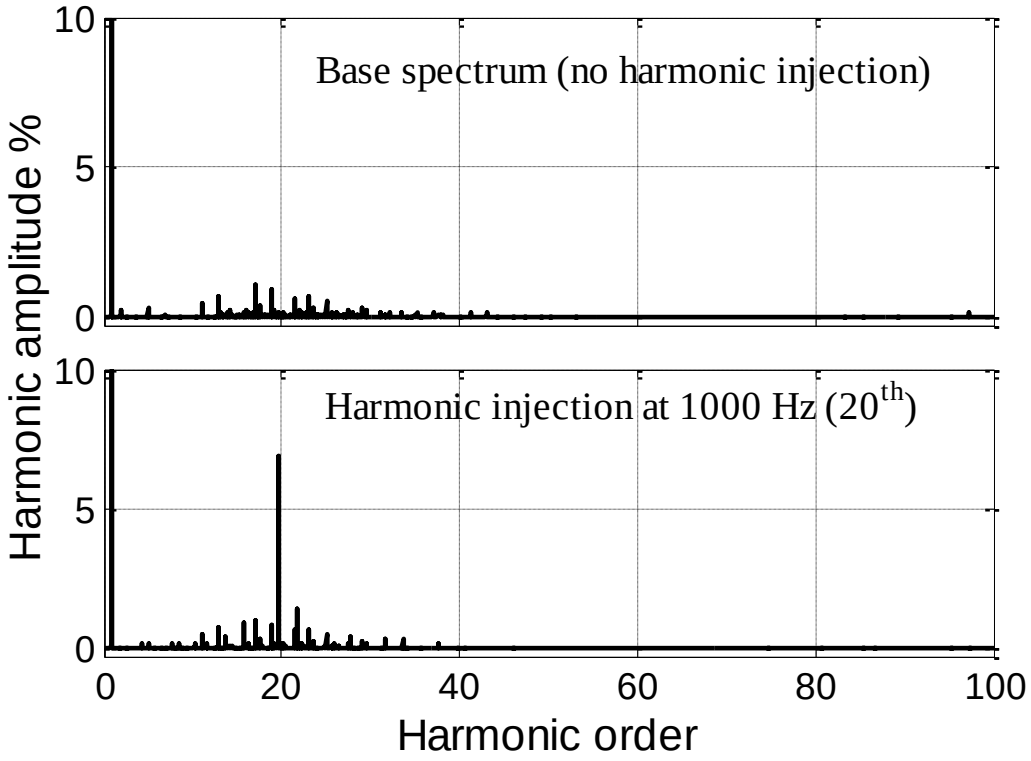
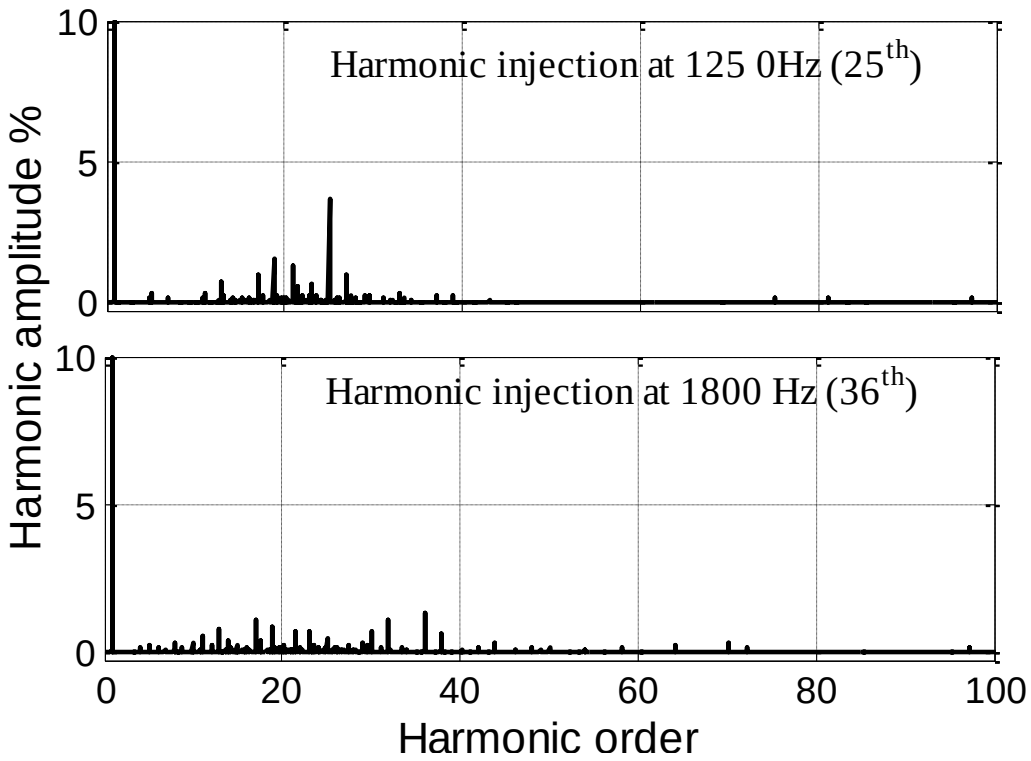
Advantage of high switching frequency:
Harmonic injection at higher orders & impedance scan at higher orders





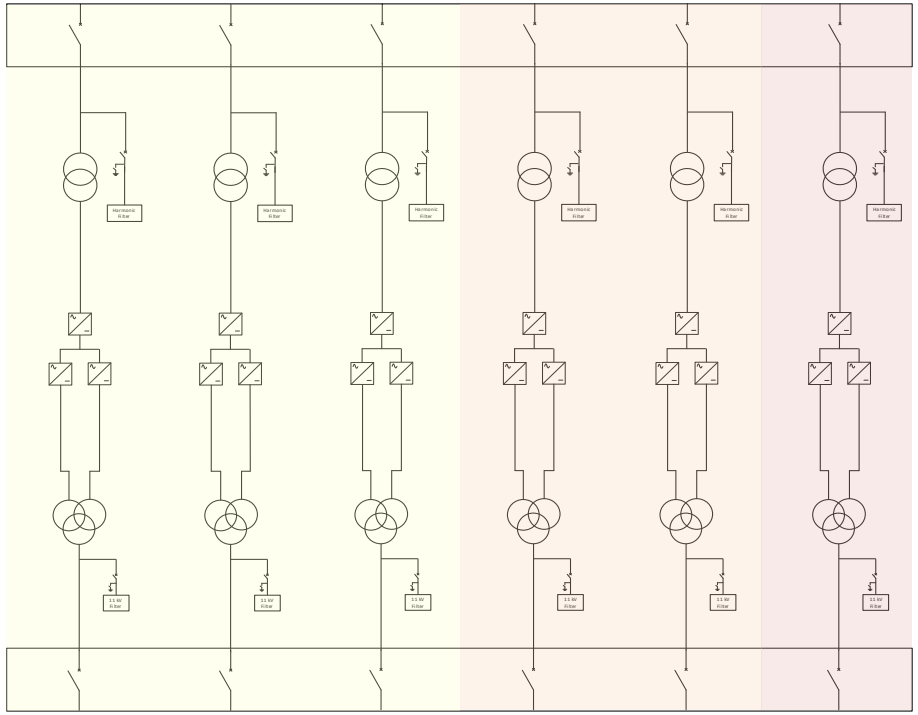
Measured voltage spectra of GEM at PCC* with disconnected DuT and 4 interleaved inverters + filter ($f_{N(PCC*)}$=50 Hz)

Source: M. Geske, P. Sadowski, M. Janssen, J. Serra Rivas, H.S. Hildebrand: The neutral-point piloted inverter topology applied to grid emulation, ECCE Conf., Darmstadt, Germany, Sep. 2024

Fast Switching MV Converters

Scalability through parallelization

- Modular design (expandable, reconfiguration possible)
- Improved harmonic content with phase-shifted PWM



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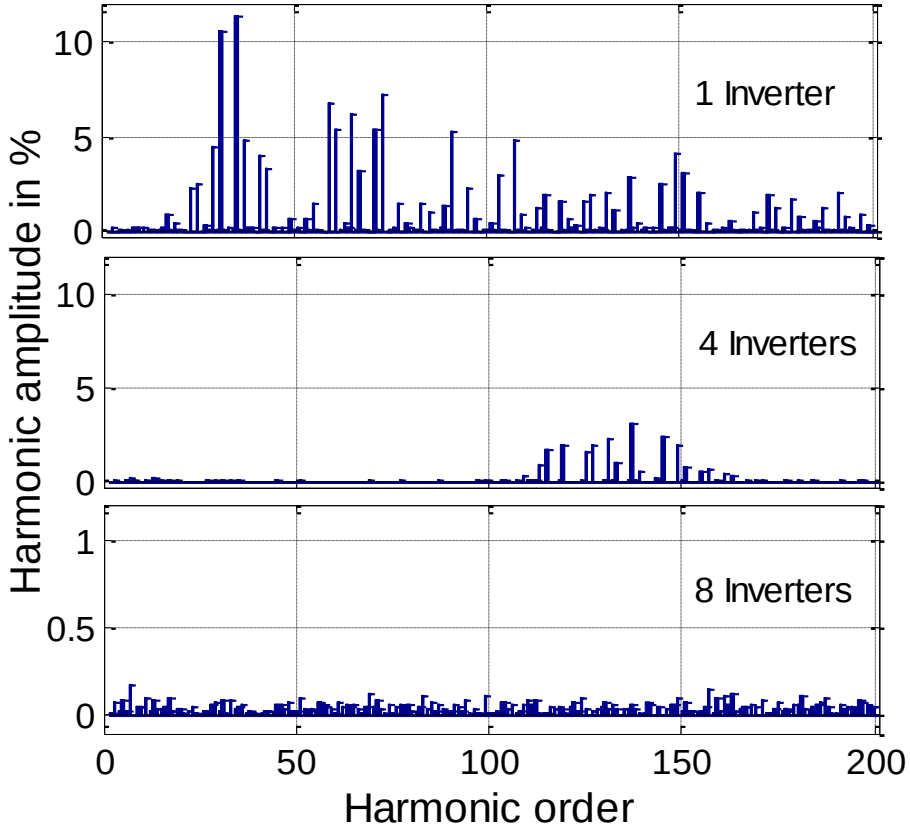
Example of modular concept for grid emulator



GEM voltage spectra: one inverter (top), four inverters (middle), eight inverters (bottom) (f_{car}=1650 Hz, no filter)

Source: M. Geske, P. Sadowski, M. Janssen, J. Serra Rivas, H.S. Hildebrand: The neutral-point piloted inverter topology applied to grid emulation, ECCE Conf., Darmstadt, Germany, Sep. 2024

Summary

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Grid emulator systems

- MV converters provide comparatively low switching frequency
- Require low THD_V and harmonic injection at higher orders, for example

Advantage of high switching frequency

- Smaller filter rating
- Higher dynamics
- Harmonic injection at higher orders

MV converter with NPP topology

- Can achieve higher switching frequency than NPC topology for same semiconductors
- Commercially available converters of MV7 series
- Scalability through parallelization of converters (expandable, reconfiguration possible)

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