GALVANICALLY ISOLATED MODULAR CONVERTERS

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Ongoing research projects related to MVDC

- **MVDC Energy Conversion Technologies and Systems**, SFOE funding
- **Multiport Energy Gateway**, SNSF NRP 70 funding
- **Solid State Resonant Conversion**, SNSF funding
- **Medium Frequency Transformer Design and Optimization**, internal funding
- **Galvanically Isolated Modular Converter**, SCCER-FURIES funding
- **High Power Multi Drive Systems operated from a MVDC Bus**, ind. funding
- **MVDC Protection Coordination**, ind. funding
- ... 

Research focus

- System design optimization
- Source-load interactions and stability studies
- Power electronic conversion technologies
- Energy storage integration
- Medium frequency transformers for galvanic isolation
Objectives

- Quantify potential and impact of MVDC systems (w.r.t. MVAC)
- Develop dynamic models and stability assessment tools
- Develop enabling power electronics technologies

Demonstration in PEL’s MV laboratory

- Efficient electrical energy conversion (less losses)
- Compact electrical energy conversion (less raw materials)
- Energy storage integration (improved energy management)

WG SC C6.31 MVDC Grids - Feasibility Study - next meeting to be held in Lausanne, January 17th - 18th, 2017

MVDC for marine distribution [1]

Stability studies

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MULTIPORT ENERGY GATEWAY (MEG)

Focus

▷ MVDC-LVDC conversion system with integrated energy storage

Converter Topology

▷ SST with multiport resonant stage [2]

Features

▷ DC transformer
▷ Soft switching
▷ Hybrid ES
▷ Three windings MFT
▷ LLC resonant circuit
▷ Efficiency

Prototype ratings

▷ $P = 0.5\,\text{MW}$
▷ $V_{MV} = 10\,\text{kV}$
▷ $V_{LV} = 750\,\text{V}$

Focus
- Bulk power conversion
- IGCT characterization & optimization
- High power magnetics design

Test setup

Characterization setup

Prototype
- $V_{DC} = 5 \text{kV}$
- $I_{max} = 2.25 \text{kA}$
Focus

- High voltage MFT design [3] - insulation coordination
- Precise parameter control - resonant operation
- High power conversion - thermal design
- Characterization of magnetic materials

Design algorithm

Electrical inputs → Dielectric distances → Optimization var ranges → Prepare data → Direct user inputs → Electrical data → Core materials data → Core dimensions data → Wire data → Data base inputs

- Winding losses calculation
- Magnetic energy calculation
- Calculate $d_w$ to match $I_{m}$
- Calculate $l_g$ to match $N_{m}$
- Core losses calculation
- Mass and volume calculation
- Hot-spot temperature calculation

Optimization engine

- $d_w = \frac{d_{w,\text{ref}}}{F_{cg}}$ 
- $d_{w} = d_{w,\text{ref}}$ 
- $l_g = \frac{L_{m,\text{ref}}}{F_{cg}}$
- $N_{m} = N_{m,\text{ref}}$
- $F_{cg}$

Save design

Prototype

- $P = 100$ kW
- $V_p = V_s = 750$ V
- $f_{sw} = 10$ kHz

GALVANICALLY ISOLATED MODULAR CONVERTER (GIMC)

Focus

- MVDC-LVAC galvanically isolated conversion system

Features

- High efficiency
- Galvanic isolation
- Modularity
- Scalability
- Reliability
- Availability

Prototype ratings

- $S = 0.5$ MVA
- $N_{\text{cells}} = 6 \times 16$
- $V_{DC} = 10$ kV
- $V_{AC} = 400$ V

Considerations

- VSI on LVAC side of SST reduces efficiency by $\approx 2 \%$ (!) [4]
- Solution with MMC + LFT preferred to overcome that issue

Research challenge

- Transformer integration into the MMC

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GIMC – TOPOLOGY AND OPERATING PRINCIPLES

- Transformer integration must achieve DC bias cancellation in magnetic core
- Two new structures are obtained
  2. Interleaved GIMC [7]
  flexible configuration
- State-space models are identical \(\Rightarrow\) same control algorithm [8]

GIMC – CELL DESIGN

Cell
- 1.2 kV / 50 A full-bridge IGBT module
- $C_{cell} = 1.9 \text{ mF}$

Thermal design \[9\]
- Cell level: detailed FEM
- Cabinet level: simplified FEM

Semiconductor losses
- Virtual Submodule concept has been utilized
- Closed-loop waveforms are approached by analytical waveforms

\[ \begin{align*}
\text{P}_{c,T,u} & = 0 \\
\text{P}_{c,T,l} & = 1 \\
\text{P}_{c,D,u} & = 0 \\
\text{P}_{c,D,l} & = 0 \\
\text{P}_{on,T,u} & = 0 \\
\text{P}_{on,T,l} & = 0 \\
\text{P}_{off,T,u} & = 0 \\
\text{P}_{off,T,l} & = 0 \\
\text{P}_{rr,D,u} & = 0 \\
\text{P}_{rr,D,l} & = 0
\end{align*}\]

\[ \begin{align*}
\text{Losses [W]} & \quad \phi \quad [\text{rad}] \\
-\pi & \rightarrow -\pi/2 \rightarrow 0 \rightarrow \pi/2 \rightarrow \pi
\end{align*}\]

- PS-PWM, DC circ
- PS-PWM, DC+2\text{nd} circ
- Time benchmark

\[ \text{Simulation time [s]} \]

\[ \begin{align*}
\text{Simulation time [s]} & \quad \phi \quad [\text{rad}] \\
-\pi & \rightarrow -\pi/2 \rightarrow 0 \rightarrow \pi/2 \rightarrow \pi
\end{align*}\]

Dielectric design

- Cell compliant to UL840 (< 1 kV\textsubscript{ac} circuit)
- Converter compliant to IEC 61800-5-1 (6.6 kV\textsubscript{ac} system, PD 1 & OV cat. I) \[10\]
- Design phase supported by FEM simulations
- Measurement in PD test setup (≤ 10 pC ✓)

Converter layout

![Converter layout diagram]

Design constraints to CAD

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PD test setup

![PD test setup image]

AC dielectric test

![AC dielectric test graph]

ENABLING TECHNOLOGIES AT PEL

High power medium voltage conversion
- Offers efficient and controllable bulk power processing [MW]
- Requires careful insulation coordination - safety
- Leads to modular designs
- Implies advanced control / communication strategies
- Reliability and availability must be ensured

Research path
- System studies
- Modeling and simulations
- Control system design
- Medium voltage high power prototyping
- Performance verification
- Publishing

It is possible in an academic research laboratory...
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