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Effects of Mixed-Frequency Voltage Stress on Dry-Type Insulation Systems

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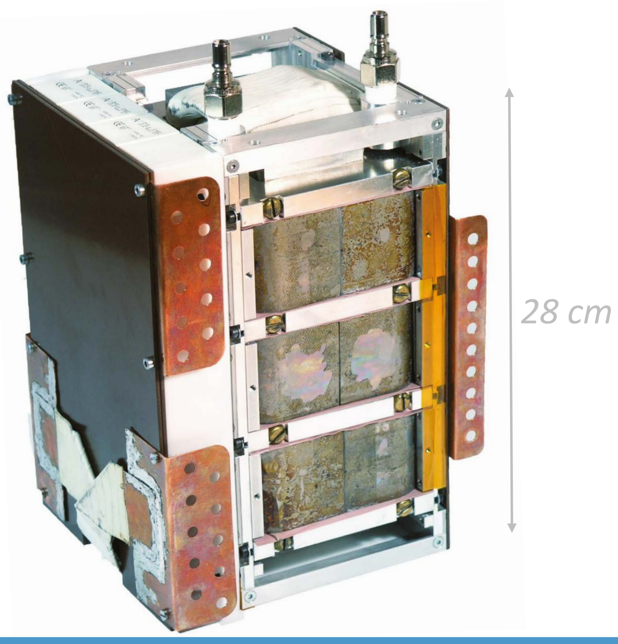
I. Introduction

The importance of power electronic converters in energy transmission and distribution networks is bound to increase due to their unprecedented flexibility in electrical power conversion and conditioning. Voltage waveforms generated with the aid of solid state switches introduce a new form of insulation stress as compared to the conventional 50 Hz sinusoidal waveforms. Their high slew rates have been shown to lead to enhanced partial discharge activity and corresponding accelerated aging of wire insulation in inverter-fed induction motors [1] as well as reduced breakdown voltages of oil-impregnated paper insulation [2]. However, apart from enhanced dielectric heating due to significant harmonics, the effects of mixed-frequency voltages on insulation materials below partial discharge inception are to a large extent unknown.

It is the goal of this project to identify the pertinent modes of degradation active under mixed-frequency stress in dry-type insulation materials which in turn helps to establish dimensioning guidelines for reliable insulation concepts, in particular for medium voltage Solid-State Transformers [3]. To this end we combine theoretical considerations on the physics of dielectrics with FEM/PEEC simulations of the electromagnetic field in the insulation system of Solid State Transformers and experimental parameter studies on polymeric specimens.

Medium-frequency (MF) transformer unit of a Solid-State Transformer (SST) ▷



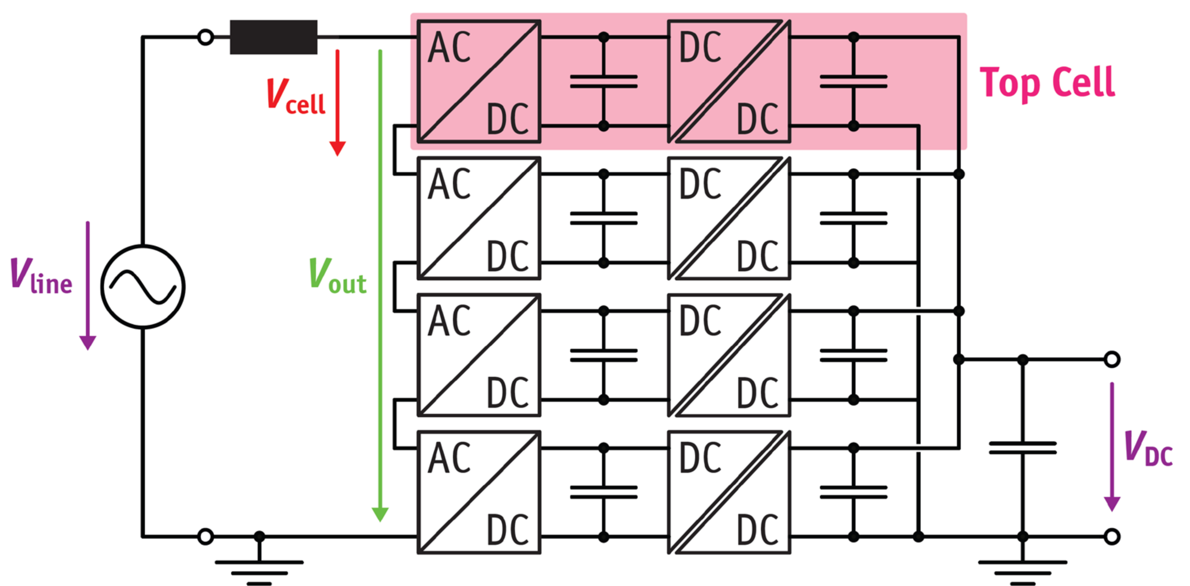
II. Solid-State Transformers (SSTs) and Mixed-Frequency Voltage Stress

MF transformer benchmark data [4]:

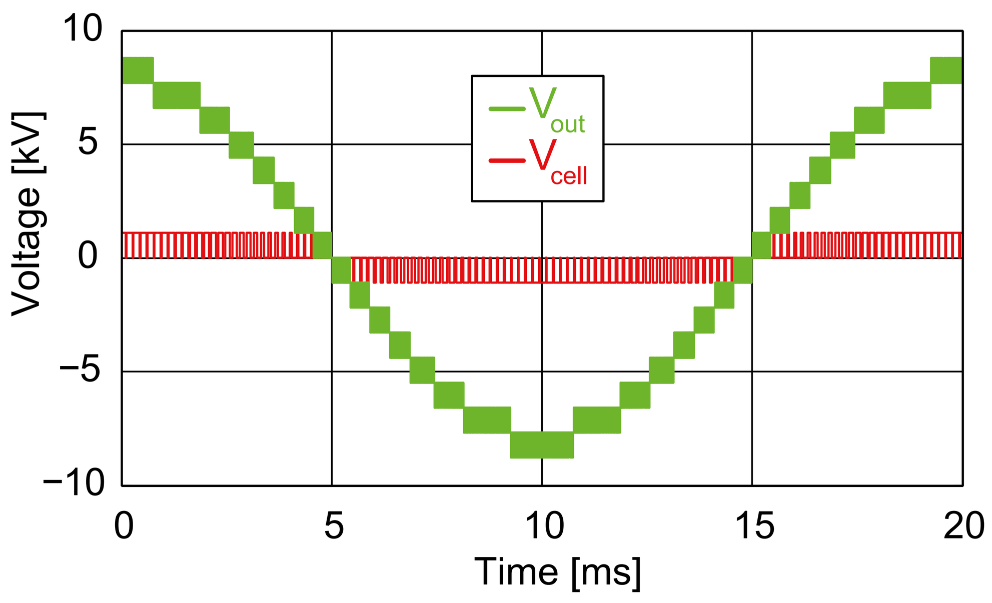
- Efficiency: 99.5 %
- Power: 166 kW (~20 kW/dm^3)
- PWM switching frequency: 20 kHz

MF transfomer insulation challenges:

- Enhanced dielectric losses (harmonics)
- Dielectric relaxation peaks and their temperature-dependence must be taken into consideration
- Evacuation of copper and core losses through insulation
- Consideration of thermal and electromechanical forces
- Control of degrading effects at metal-insulator interface



AC-DC Solid-State Transformer topology △



Top cell mixed-frequency voltage △

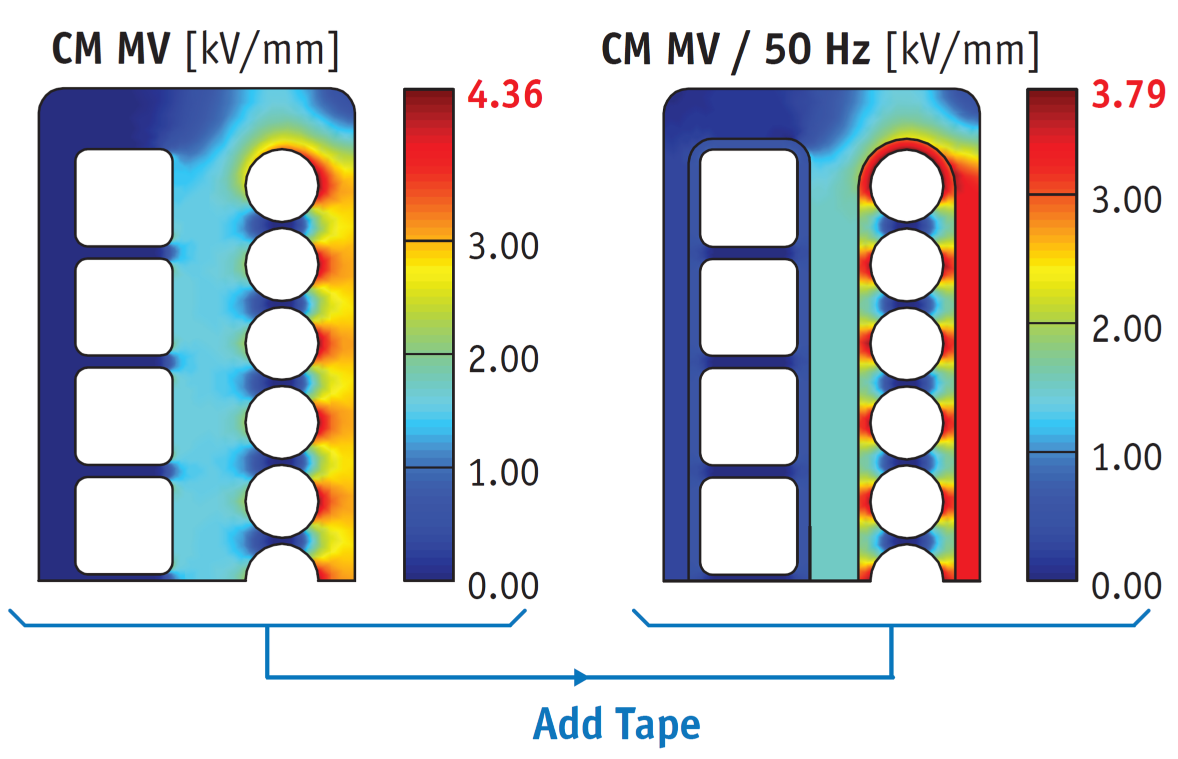
III. Field Simulations and New Insulation Concepts

Electric/magnetic FEM (2D) / PEEC (3D) analysis [3]:

- Electric field stress
- Dielectric loss
- Influence of voltage wave effects on insulation stressing
- Evaluation of new insulation concepts, e.g.

Semiconducting tape around MF transformer windings

- Conduction selectively active for 50 Hz component (not for MF)
- Homogenization of low-frequency electric field component
- Partial discharge barrier



Electric field norm with/without semiconducting tape △

IV. Experimental Setup

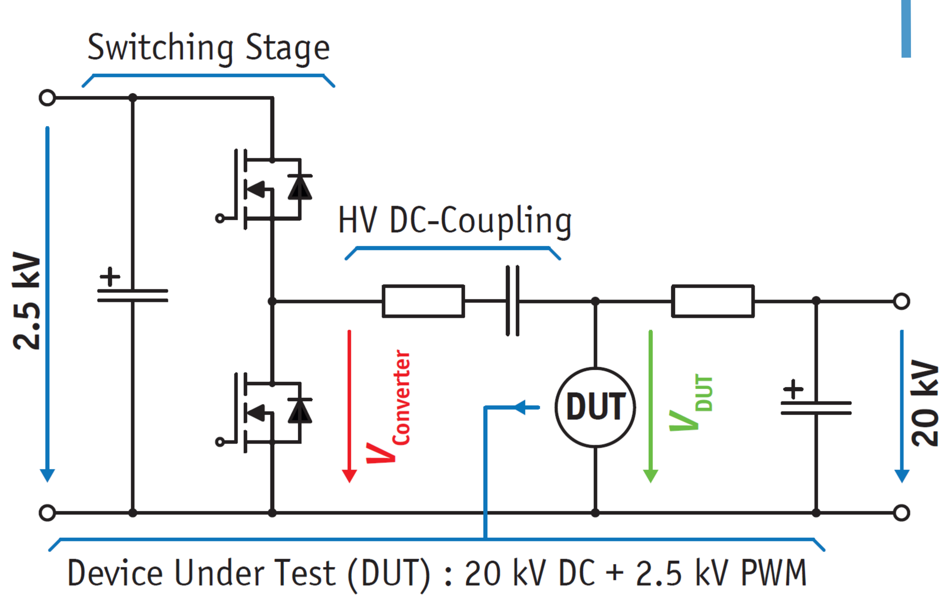
Mixed-frequency test bench

Adjustable parameters:

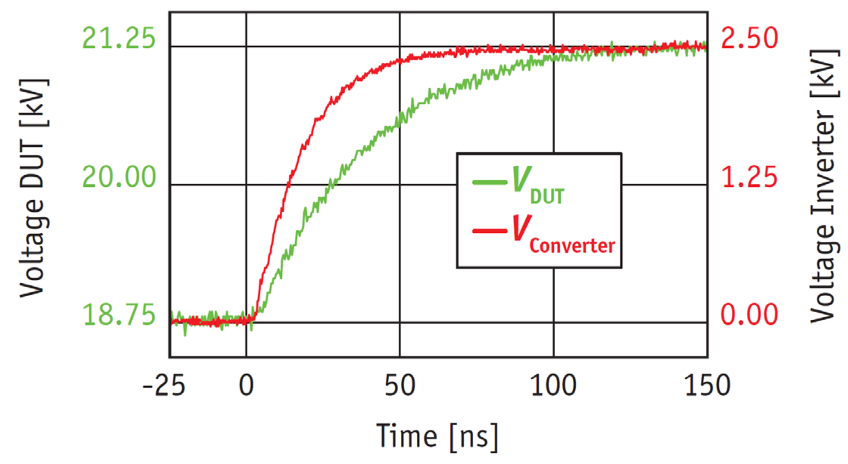
- DC offset (0..20 kV)
- Pulse amplitude (0..2.5 kV)
- Repetition frequency (0.1..5 kHz)
- Slew rate (up to 30 kV/µs)

Modular dielectric spectroscopy for aging diagnostics

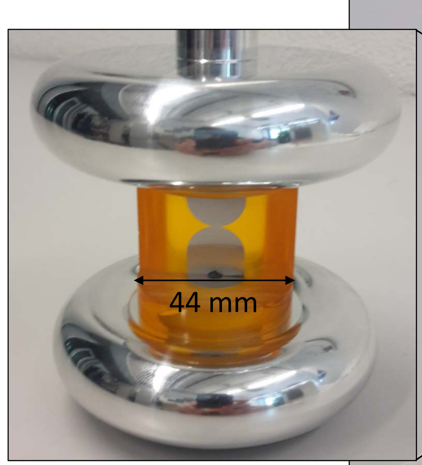
- Low voltage setup for offline diagnostics
- Frequency range: 1 Hz to 100 kHz on 5 pF specimen capacitance
- High voltage setup for online monitoring (under assessment)



Pulses from the half-bridge are capacitively coupled onto the HV DC voltage. △

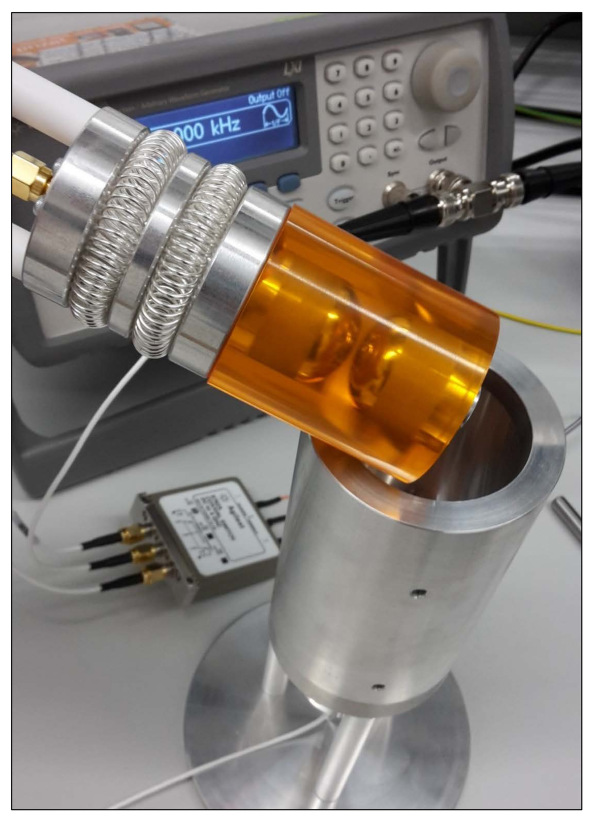


PWM switching transition △



Recessed specimen △ *(epoxy polymer) with guard toroids*

△ *Test cell with mixed-frequency voltage generator mounted below*



△ *Modular dielectric spectroscopy setup for offline aging diagnostics*

V. References and Acknowledgement

[1] P. Wang et al.; "The Inuence of Repetitive Square Wave Voltage Parameters on Enameled Wire Endurance"; IEEE Transactions on Dielectrics and Electrical Insulation, 2014.
[2] T. Koltunowicz et al.; "The inuence of square voltage waveforms on transformer insulation breakdown voltage"; CEIDP Annual Report, 2014.
[3] T. Guillod et al.; "Characterization of the voltage and electric field stresses in multi-cell solid-state transformers"; Proc. of the Energy Conversion Congr. and Expo. (ECCE), 2014.
[4] G. Ortiz et al.; "Medium Frequency Transformers for Solid-State-Transformer Applications – Design and Experimental Verification"; IEEE PEDS Conference, 2013.

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