High-Power Medium Frequency Transformers in Medium Voltage Power Electronics

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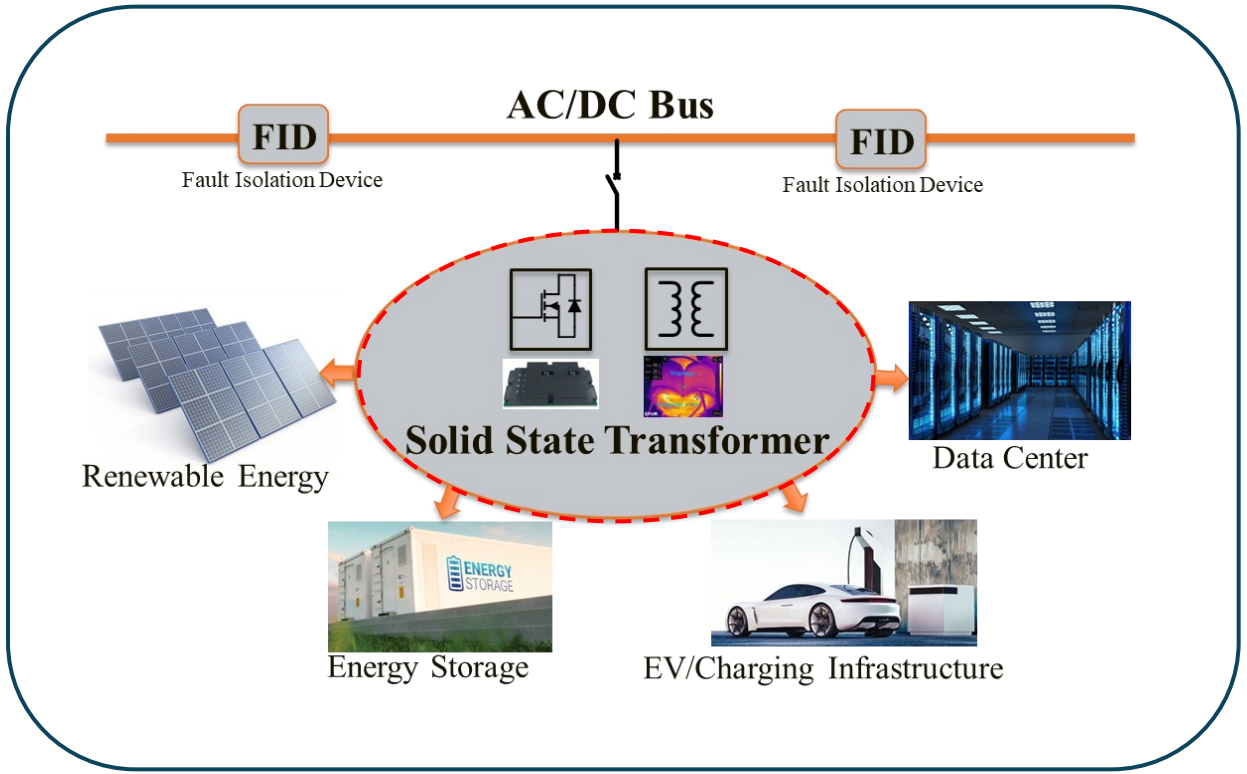
Arizona State University

High-Power MFTs in MV Power Electronics



Energy Internet

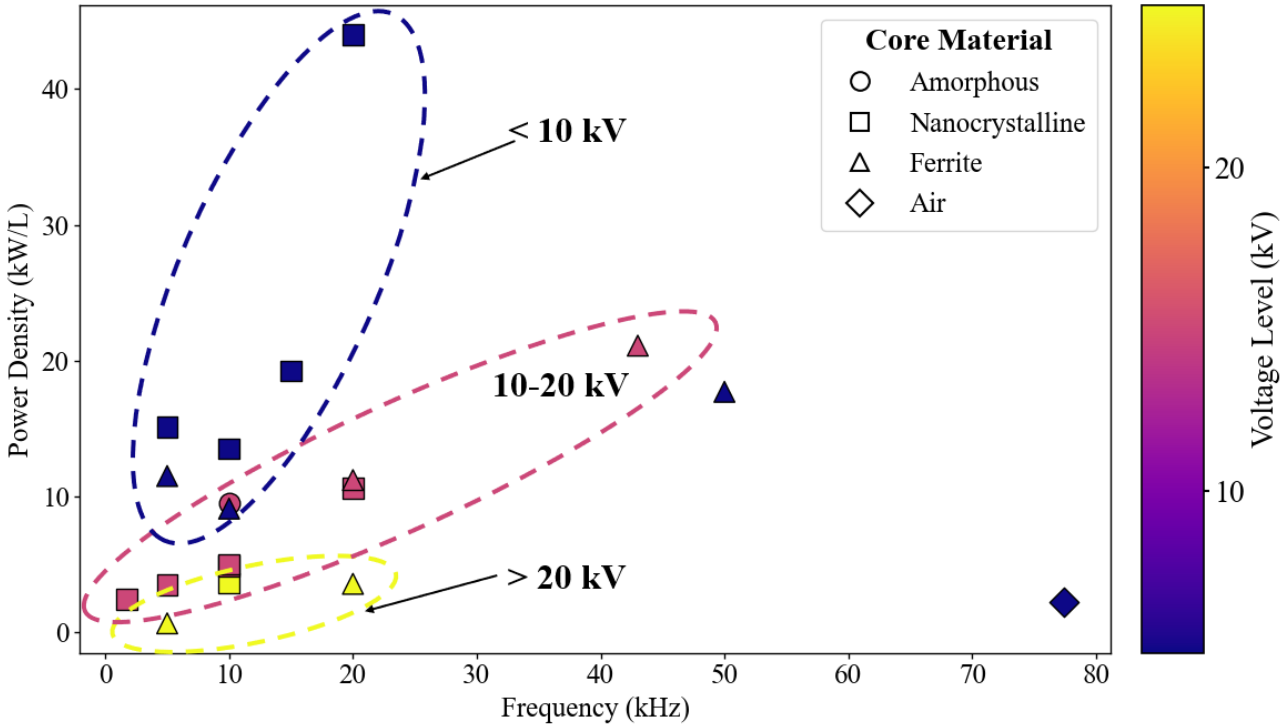
Energy Router

High-Power MFTs in MV Power Electronics

	Power Rating (kW)	Frequency (kHz)	Power Density (kW/L)	Core Material	Dielectric Material	Cooling Method	Insulation Voltage (kV)	MV Applications
ABB 2002	350	10	9.5	Amorphous	Solid	De-ionized Water	28(*) 38(**) 95(****)	Electronics transformer
ABB 2014	150	1.75	2.4	Nanocrystalline	Oil	Oil-immersed	34.5(**) 75(****)	PETT
ABB 2017	240	10	3.6	Nanocrystalline	Solid - Cast Resin	air	53(*) 70(**) 150(****)	SST
EPFL 2019	100	10	9.1	Ferrite	Air	Air cooling +heatsink	4(*)	SST
CUT 2021	50	5	0.65	Ferrite	Oil	Oil-immersed	125(***)	HVDC
KMUST 2022	80	43	21.1	Ferrite	Epoxy	Air	42(**)	Power Electronic Transformer
ETH 2022	166	77.4	2.2	Air	NOMEX pressboards&Air	air	6.36(**) 9.6(***)	SST
UT Austin 2023	100	20	10.6	Nanocrystalline	SilGel 612	Air cooling +3D printed heatsink	14 (*) 25(***)	SST
UTK 2023	50	10	13.5	Nanocrystalline	Silicone Encapsulation	Air cooling	7.8(*)	MV DCDC converter
TU/e & ABB 2024	166	20	3.56	Ferrite	ester liquid	Immersed Liquid cooling	28.2(*) 54(**) 95(****)	SST

*** Partial discharge insulation test. ** Applied voltage insulation test. *** DC insulation test **** BIL**

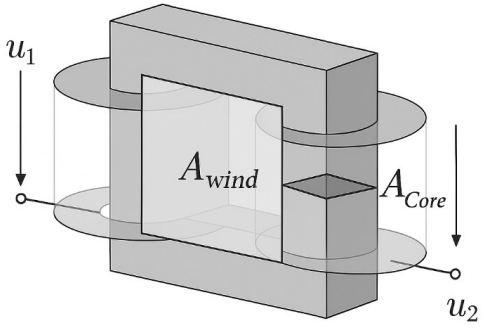
High-Power MFTs in MV Power Electronics



High-Power MFTs in MV Power Electronics

$$A_{core} = \frac{U}{4B_{max}fN} \qquad A_{wind} = \frac{2NI}{K_u J_{rms}}$$

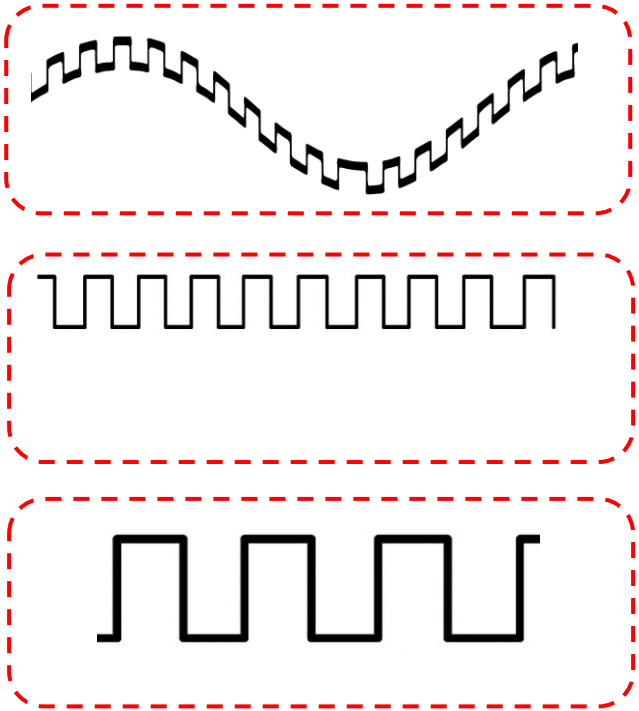
$$A_P = A_{core}A_{wind} = \frac{P}{2K_u J_{rms} B_{max} f}$$



P	Rated Power
K_u	Window Utilization Factor (Insulation)
J_{rms}	Winding Current Density (Cooling)
B_{max}	Flux Density Amplitude (Magnetic material)
f	Frequency

Challenges and Solutions in MFT Insulation Design and Test

Complex Voltage Stress and Electric Field Distribution



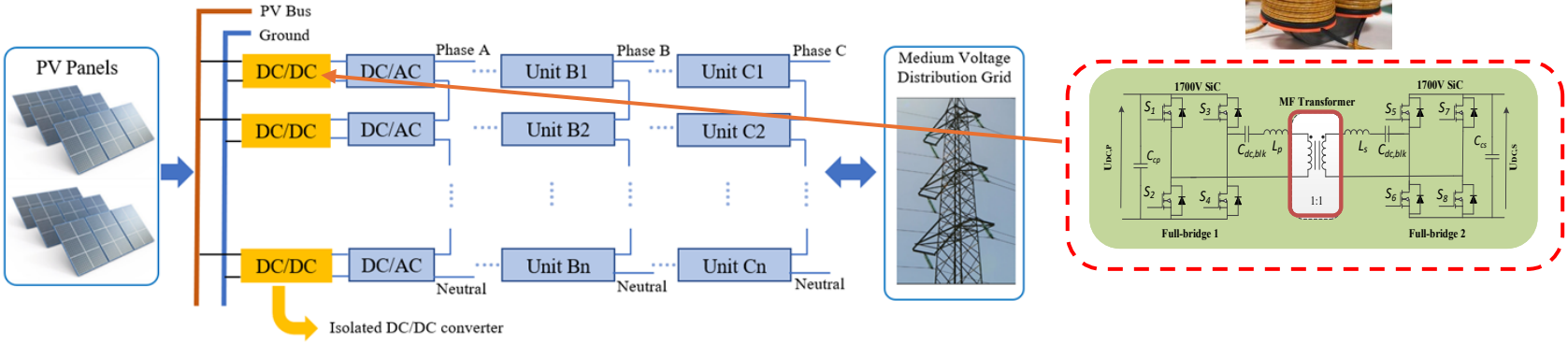
MV ac modular topology
input-series-output-parallel (ISOP)

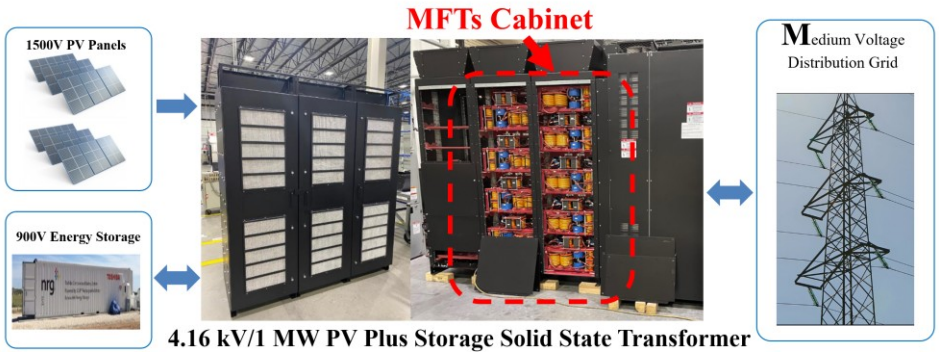
MV dc modular topology

Non-modular topology

Challenges and Solutions in MFT Insulation Design and Test

Complex Voltage Stress and Electric Field Distribution





DOE DE-EE0008348 Award Amount: $3 million, PI: Dr. Alex Q. Huang

Challenges and Solutions in MFT Insulation Design and Test

What Are the MFT Insulation Test Standards?

IEEE Std C57.12.00	IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers
IEEE Std C57.12.90	IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers
IEEE Std C57.113	IEEE Recommended Practice for **Partial Discharge** Measurement in Liquid-Filled Power Transformers and Shunt Reactors
IEEE Std C57.98	IEEE Guide for Transformer Impulse Tests

IEEE Std C57.12.01	IEEE Standard for General Requirements for Dry-Type Distribution and Power Transformers
IEEE Std C57.12.60	IEEE Standard for Thermal Evaluation of Insulation Systems for Dry-Type Power and Distribution Transformers
IEEE Std C57.12.91	IEEE Standard Test Code for Dry-Type Distribution and Power Transformers
IEEE Std C57.124	IEEE Recommended Practice for the Detection of **Partial Discharge** and the Measurement of Apparent Charge in Dry-Type Transformers

IEEE Standards for LFT Insulation

Challenges and Solutions in MFT Insulation Design and Test

What Are the MFT Insulation Test Standards?

Test sequence

The dielectric tests should be performed in the following preferred sequence:

a) Lightning impulse tests

b) Applied voltage test

c) Induced voltage test

d) Partial discharge test

Partial Discharge Test

Partial discharge (PD) tests are intended to verify that the internal insulation is free from damaging discharges .

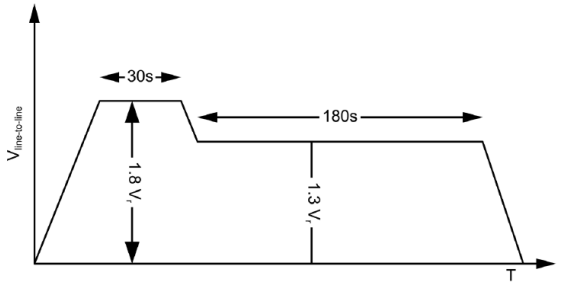


Figure 27—Partial discharge test voltage application

Liquid-Immersed: 10 pC Dry type: 50 pC

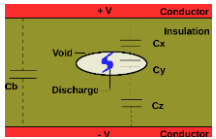
Challenges and Solutions in MFT Insulation Design and Test

What Are the MFT Insulation Test Standards?

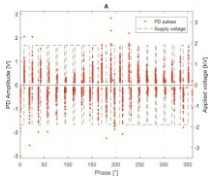
IEEE SA STANDARDS ASSOCIATION

IEEE P3105 (Recommended Practice for Design and Integration of Solid-State Transformers in Electric Grid)

lightning impulses are unlikely to be imposed directly on the MFT, the isolation barrier is augmented by additional elements to meet lightning impulse requirements



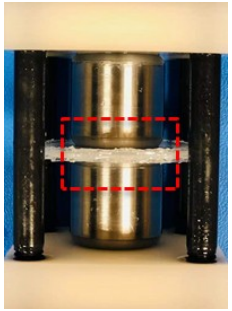
Existing standards which relate to LFT reliability or lifetime, such as **partial discharge** testing, may be over-conservative if imposed on the MF transformer without considering the specific operational conditions

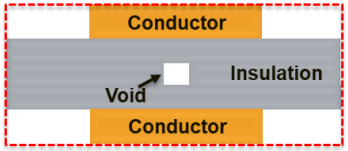


Dielectric stress of MFT is totally different from the LFT due to the MV power electronics system topologies and semiconductors power devices.

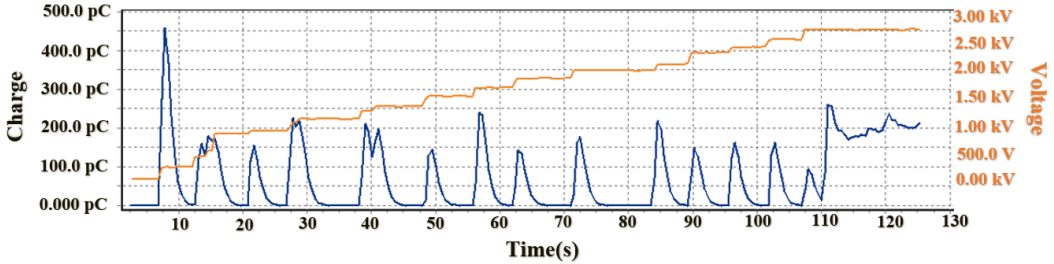
Challenges and Solutions in MFT Insulation Design and Test

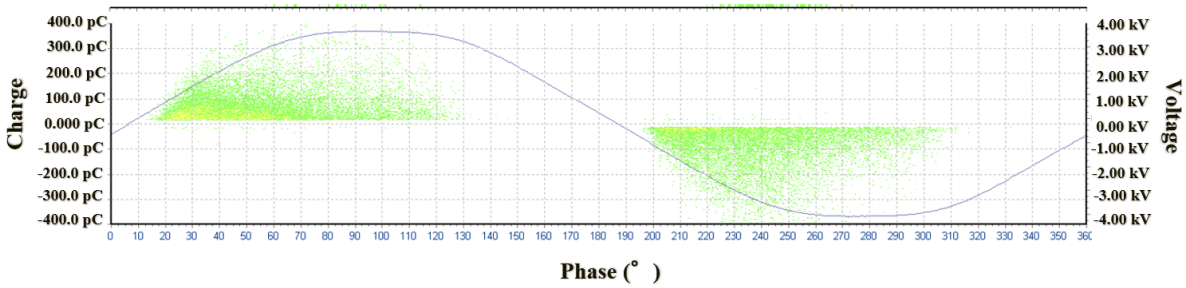
Partial Discharge Under Medium Frequency High dv/dt Waveform





❖ **Internal void test sample**

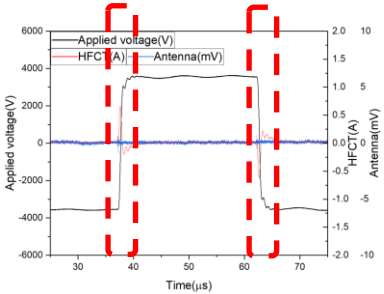


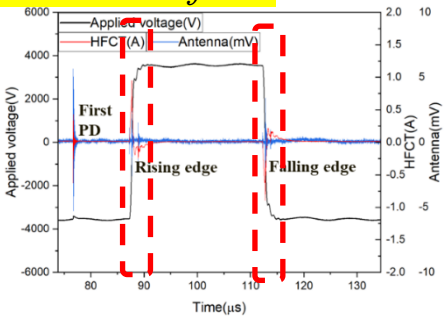


❖ **PD pattern diagram at AC 60 Hz peak-to-peak 7.6 kV**

Challenges and Solutions in MFT Insulation Design and Test

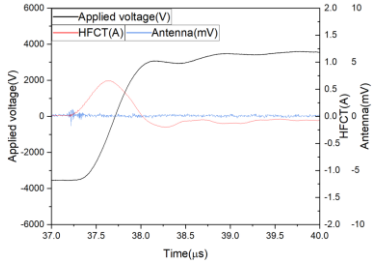
Partial Discharge Under Medium Frequency High dv/dt Waveform

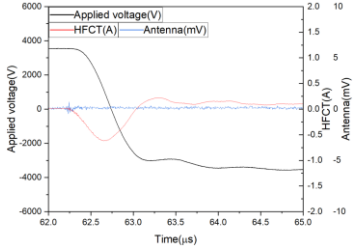




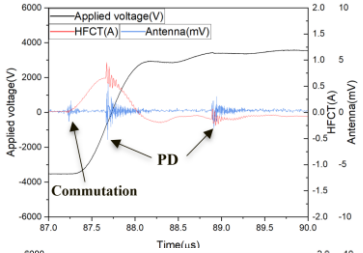
Global waveform

Without PD

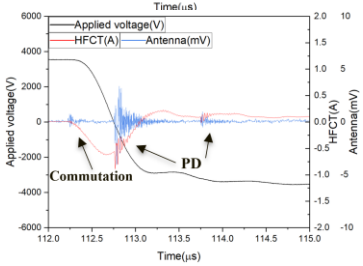




PD



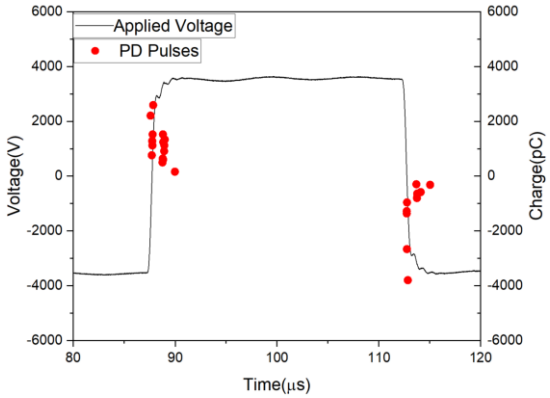
Rising edge



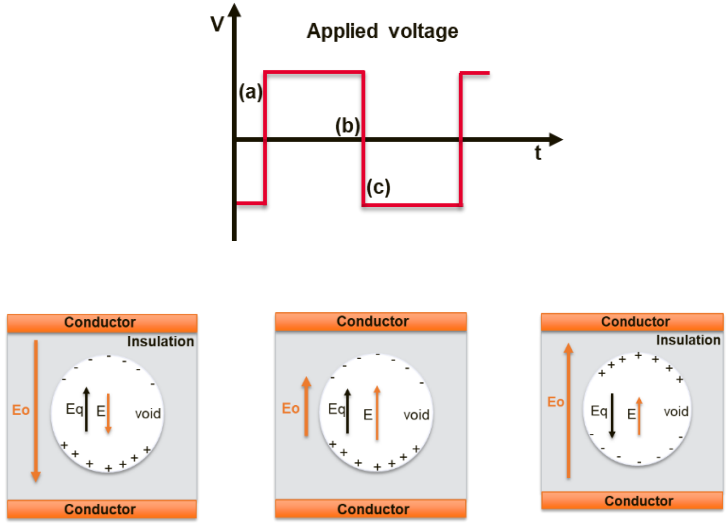
Falling edge

Challenges and Solutions in MFT Insulation Design and Test

Partial Discharge Under Medium Frequency High dv/dt Waveform

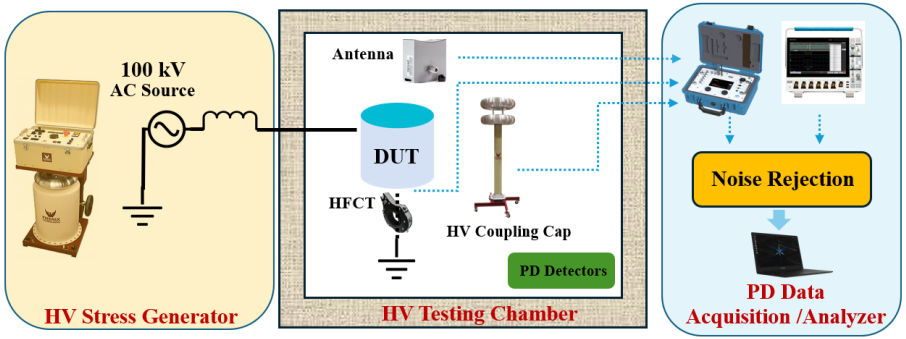


❖ **PD pattern diagram**
under 20 kHz peak-to-peak 7 kV PWM waveform



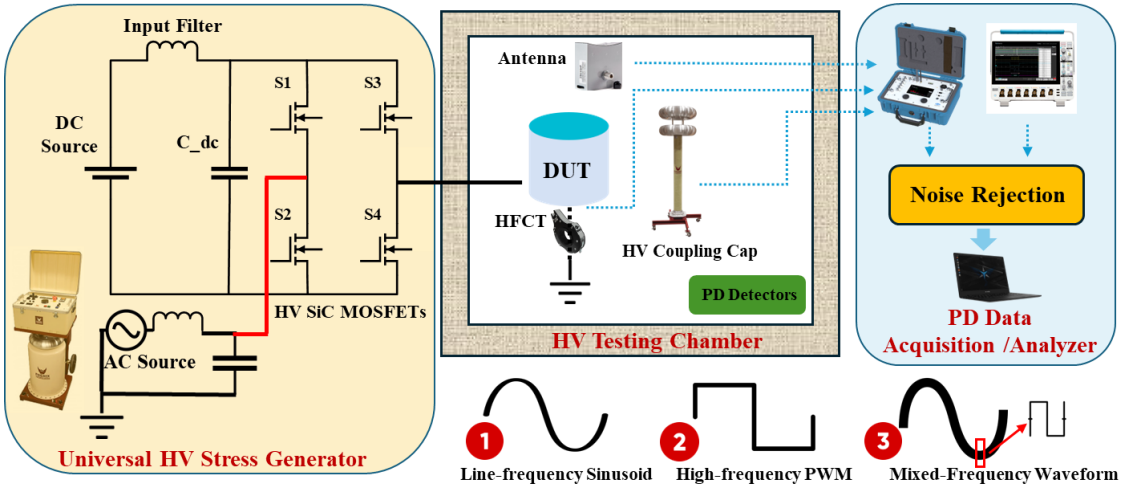
❖ **Simplified model for PD occurrence**
E_q is the field caused by the space charge deposited by a discharge;
E_0 is the geometric field ; E is the resulting field in the cavity.

Challenges and Solutions in MFT Insulation Design and Test



100 kV 60Hz Partial Discharge Test Platform

Challenges and Solutions in MFT Insulation Design and Test



100 kV Multi-function Partial Discharge Test Platform

- Multiple HV Waveforms
- Test Voltage : 0 V – **100** kV
- Low background noise: < 3 pC
- Overcurrent Protection

Thank You!

Related Publications

1. **Z. Guo** and A. Q. Huang, “Characterizations of Partial Discharge in Modern Power Electronics,” in IEEE Journal of Emerging and Selected Topics in Power Electronics, doi: 10.1109/JESTPE.2024.3417803
2. **Z. Guo** et al., "*A Novel High Insulation 100 kW Medium Frequency Transformer,*" in IEEE Transactions on Power Electronics, 2022, doi: 10.1109/TPEL.2022.3205646.
3. **Z. Guo**, A. Q. Huang, R. E. Hebner, G. C. Montanari and X. Feng, "*Characterization of Partial Discharges in High-Frequency Transformer Under PWM Pulses*," in IEEE Transactions on Power Electronics, vol. 37, no. 9, pp. 11199-11208, Sept. 2022, doi: 10.1109/TPEL.2022.3169747.
4. **Z. Guo**, R. Yu, W. Xu, X. Feng and A. Q. Huang, "*Design and Optimization of a 200-kW Medium-Frequency Transformer for Medium-Voltage SiC PV Inverters*," in IEEE Transactions on Power Electronics, vol. 36, no. 9, pp. 10548-10560, Sept. 2021, doi: 10.1109/TPEL.2021.3059879.
5. **Z. Guo**, W. Xu, A. Vetrivelan and A. Q. Huang, "Magnetic Design of a 4.16 kV/1 MW Medium Voltage PV Plus Storage Solid State Transformer (PVS-SST)," 2023 IEEE Applied Power Electronics Conference and Exposition (APEC), Orlando, FL, USA, 2023, pp. 1-5, doi: 10.1109/APEC43580.2023.10131543.
6. **Z. Guo**, C. Chen, Z. Chen and A. Q. Huang, "A High Power High Isolation Medium Frequency Transformer With A Planar Matrix Structure," 2023 IEEE Energy Conversion Congress and Exposition (ECCE), Nashville, TN, USA, 2023, pp. 5827-5830, doi: 10.1109/ECCE53617.2023.10362495.
7. **Z. Guo**, C. Chen, R. Yu and A. Q. Huang, "A High Power 200kW Medium Frequency Transformer With Improved Thermal Management," 2023 IEEE Energy Conversion Congress and Exposition (ECCE), Nashville, TN, USA, 2023, pp. 5587-5591, doi: 10.1109/ECCE53617.2023.10362391.
8. **Z. Guo**, A. Q. Huang and, X. Feng, "*Comparison of Partial Discharge (PD) Characterizations under 60 Hz Sinusoidal Waveform and High-frequency PWM Waveform*," 2022 IEEE Energy Conversion Congress and Exposition (ECCE).
9. **Z. Guo**, T. Chen, R. Yu and A. Q. Huang, "*GaN-based ±5kV/100kHz PWM Generator for Advanced Partial Discharge Characterization*," 2021 IEEE Energy Conversion Congress and Exposition (ECCE), 2021, pp. 5894-5898, doi: 10.1109/ECCE47101.2021.9595274.