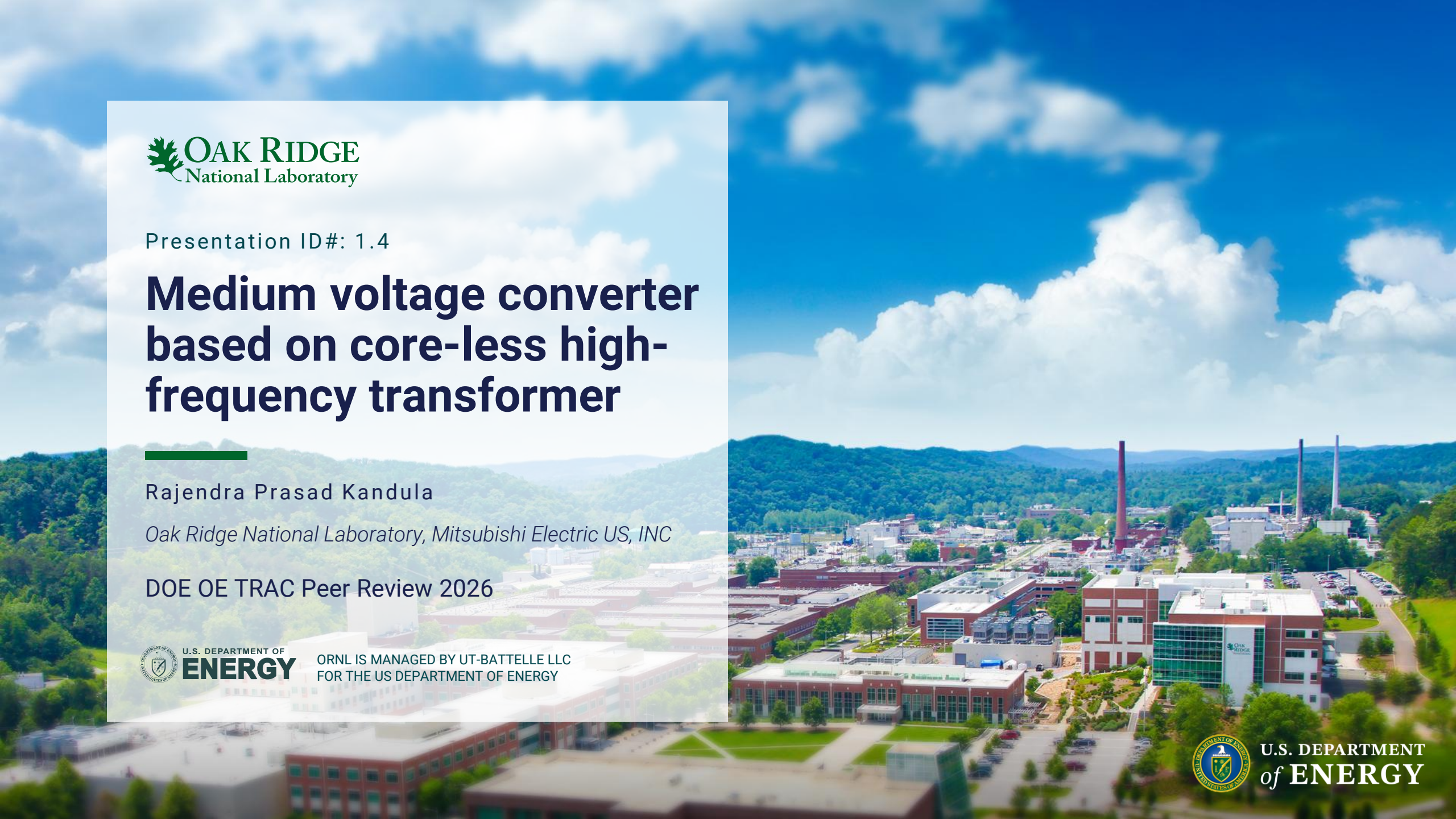


OAK RIDGE National Laboratory

Presentation ID#: 1.4

Medium voltage converter based on core-less high-frequency transformer

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DOE OE TRAC Peer Review 2026

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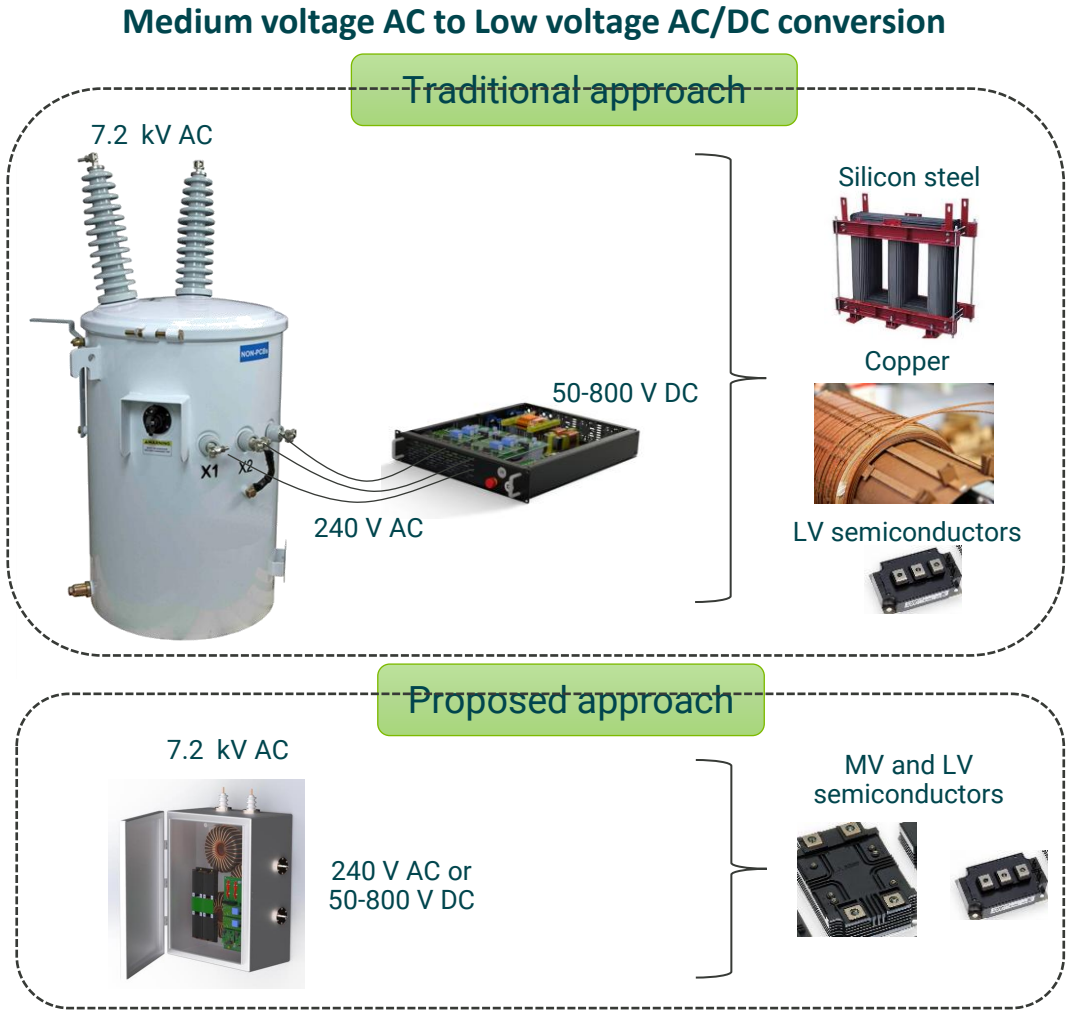
Project Overview

- Project Description: Development of Medium Voltage (MV) converter based on core-less high-frequency transformer
- Period of Performance: 10/01/2025 to 07/30/2026
- Award Amount: $1,200,000
- Prime Awardee: ORNL
- Partners: MITSUBISHI ELECTRIC US, INC
- Technology Area: Advanced Transformers, Advanced Power Electronics
- Alignment/Supports strategic pathway: Grow
- The proposed innovations in this project support a more flexible, scalable, and future-ready distribution system.
  - High-frequency power-electronics-based approach enables the interconnection of the Medium Voltage AC (MVAC) and Low Voltage AC/Low Voltage DC (LVAC/LVDC) distribution networks in the future grid.
  - The core-free transformer solution reduces dependence on constrained materials, helping mitigate supply-chain risks and improve the availability and reliability of critical grid infrastructure.
  - Coreless approach simplifies the insulation-management challenges and enable the usage of new technology of 6.5 kV SiC devices.

Problem Statement

Develop an isolated medium voltage (MV) converter (2.4 kV, 17 kVA) with core-less high frequency transformer to address the following issues in modern grid:

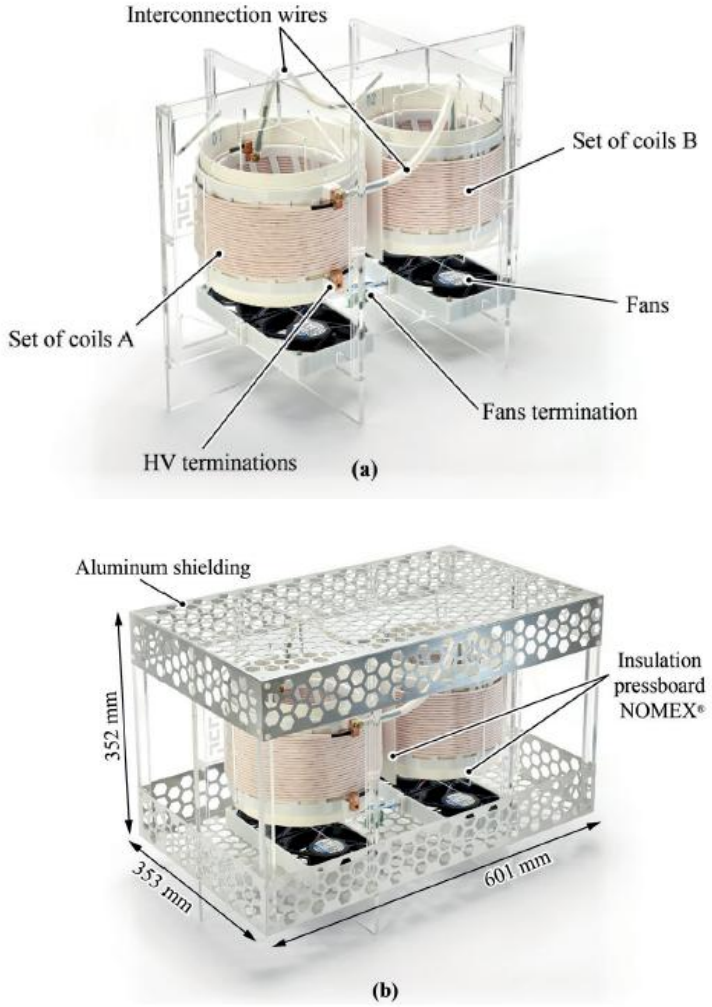
- Supply chain issues with the availability of traditional MV/LV transformers.
- Insulation management of the transformer – a major challenge at MV.
- Utilization of 6.5 kV silicon carbide (SiC) devices in high frequency (HF) applications.



Literature Survey

- In some specialized applications such as aircraft where weight of the transformer core is a major concern, core-less transformers are proposed [1].
- Authors have adopted a solenoid type of construction which will require appropriate shielding from stray electric fields.
- Exploration of co-axial type of structures such as toroids may address shielding issues in much more effective way.
- In addition, the authors have developed the concept for a 10 kV DC to LVDC power conversion application, which uses 10 kV SiC devices.
- There is no implementation of MVAC to LVAC or LVDC converter based on core-less transformer in literature.

Photo of the realized 166 kW/7 kV ACT. (a) Without shielding. (b) With aluminum conductive shielding



[1] Piotr Czyz, et'al. "Design and Experimental Analysis of 166 kW Medium-Voltage Medium-Frequency Air-Core Transformer for 1:1-DCX Applications " IEEE Journal Of Emerging And Selected Topics In Power Electronics, Vol. 10, No. 4, August 2022

Technical Approach

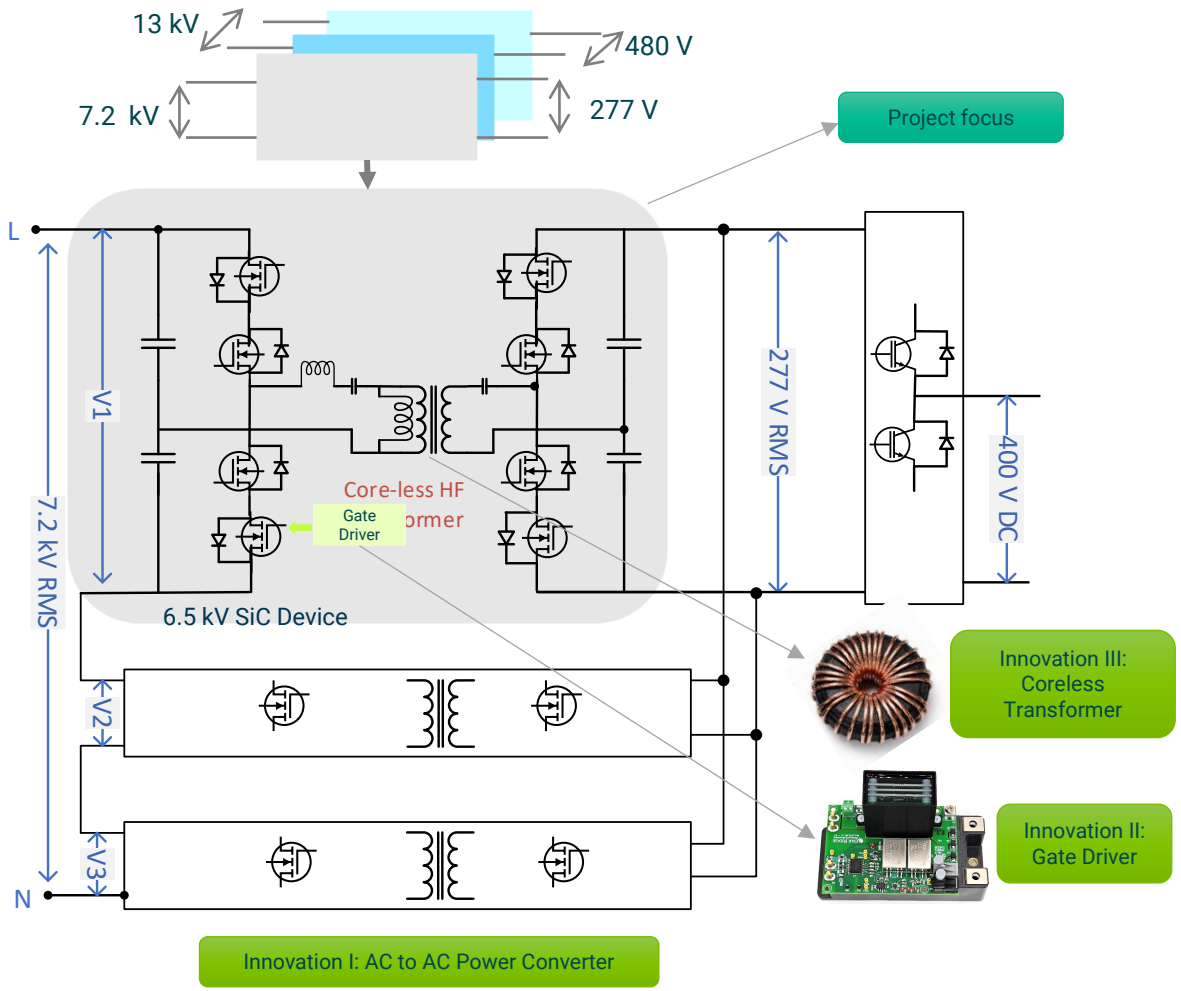
Challenges

- Main challenges for medium voltage converters.
  - Voltage balancing (V1=V2=V3) necessitating coordinated controls of multiple blocks.
  - Insulation management.
- Core-less transformer needs to operate at high frequency to keep size small.
- Operating MV semiconductors at 100s of KHz.

Approach

- Modular approach with 6.5 kV SiC devices.
- Direct AC/AC building block with fixed-frequency resonant stage.
  - ***Inherent and passive balancing.***
  - Soft switching allows high frequency operation (100 kHz).
- Controls and/or low voltage DC (LVDC) conversion are done on the LV side.

Schematic of MVAC to LVAC/LVDC Converter



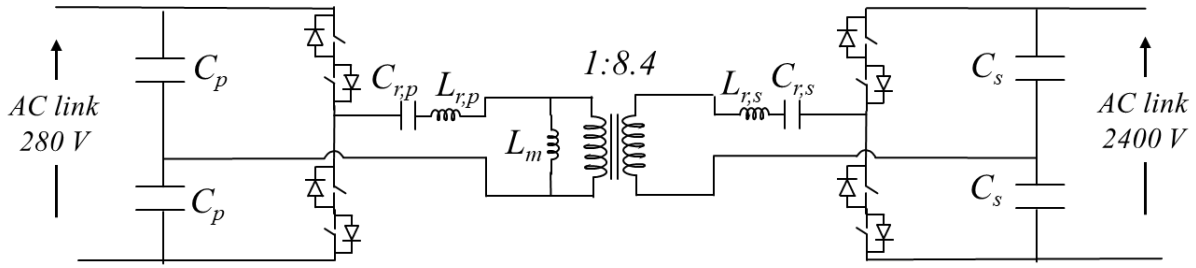
Timeline

Time	Tasks	Tasks
Year 1: Component development	Gate drive development for 6.5 kV SiC device	
	6.5 kV SiC device characterization	
	Converter verification through simulation studies	
	2.4 kV/280 V AC, 100 kHz, 15 kW transformer design and build	
Year 2: Converter development		Converter fabrication
		Converter test at 2.4 kV AC, 15 kW

Direct AC/AC Converter Building Block

Challenge: Design of transformer magnetizing inductance (Lm) to achieve zero voltage switching (ZVS) across the entire voltage and power range.

Schematic of proposed converter simulated for MVAC to LVAC application



$$P = 13\ kW, V_{HV} = 2400\ V, V_{LV} = 277\ V$$

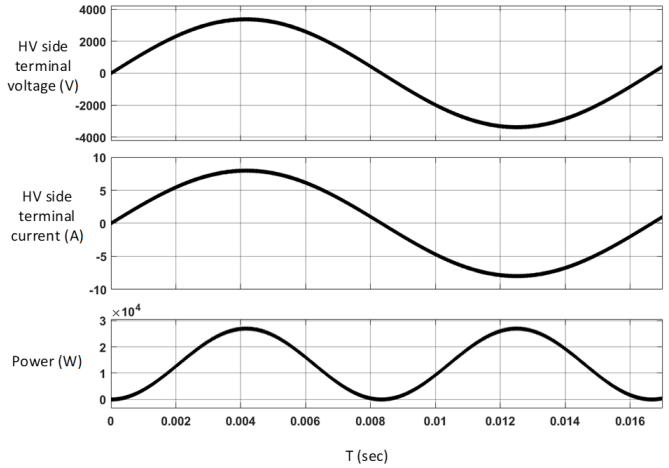
$$L_m = 250\ uH, F_s = 100\ kHz, N = 8.4$$

$$L_{rp} = 2.1\ uH, C_{rp} = 1.63\ uF, L_{rs} = 53\ nH,$$

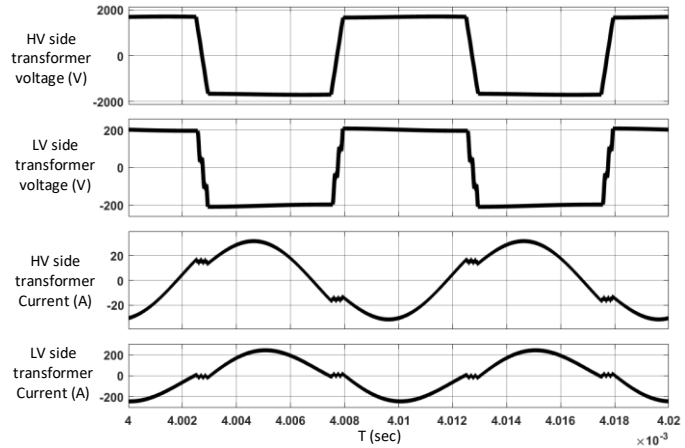
$$C_{rs} = 115\ mF, C_p = 1.25\ uF, C_s = 28.8\ uF$$

Proposed Bi-directional resonant converter shows ZVS operation 10% to 90% of rated voltage

Terminal voltages and currents for LV to MV power flow

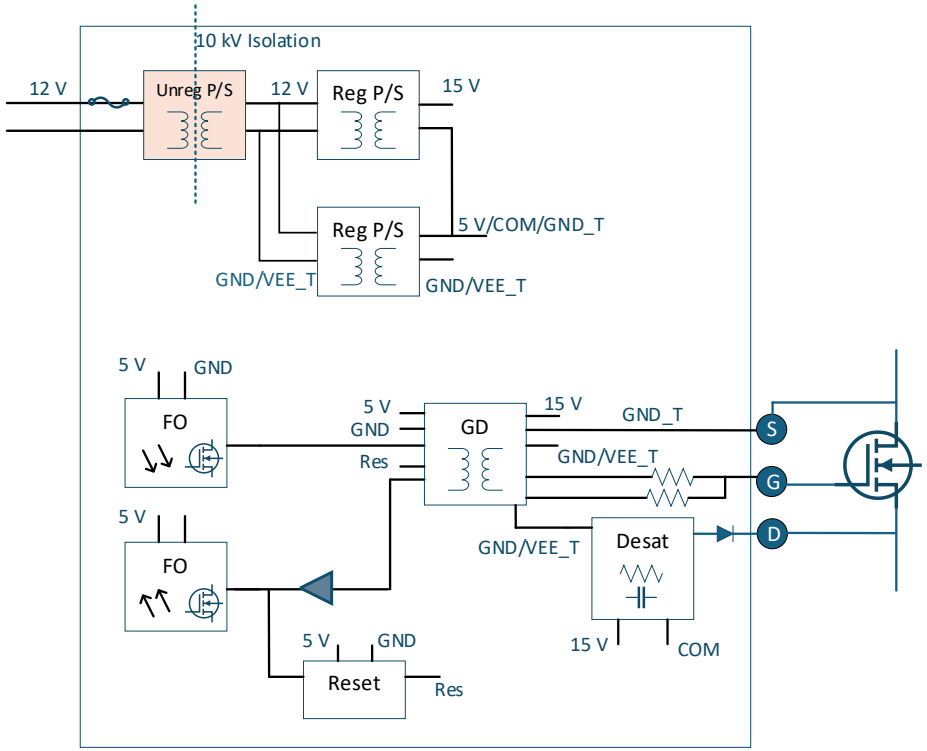


Switching voltages and currents for LV to MV power flow



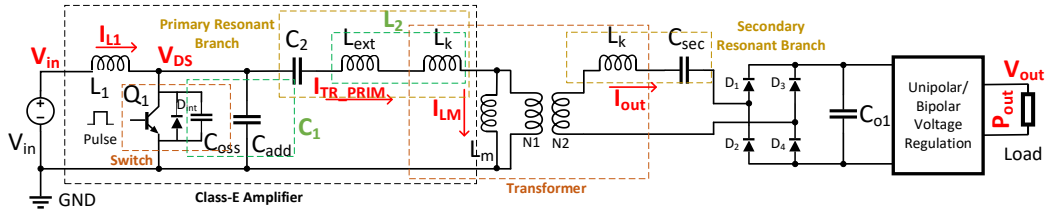
Integrated 4 kV Class Gate Drive

Schematic of Gate Drive For Medium Voltage Semiconductors

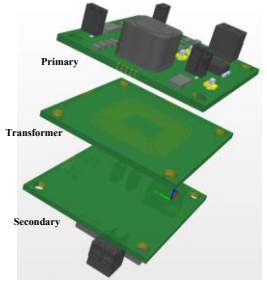


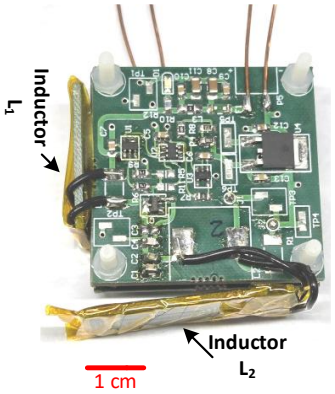
Challenge: Power supply with Medium voltage (10 kV) isolation

Schematic of Class E inverter based 10 kV Isolated power supply

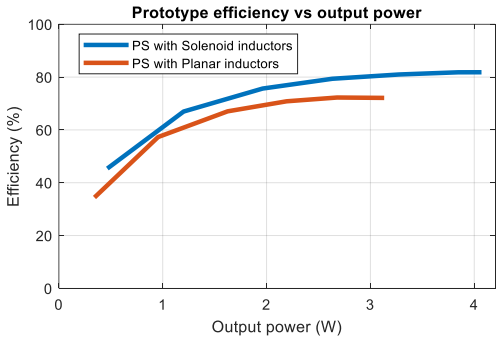


4 W 12 V 10 kV Isolated P/S Operating at 13.9 MHz





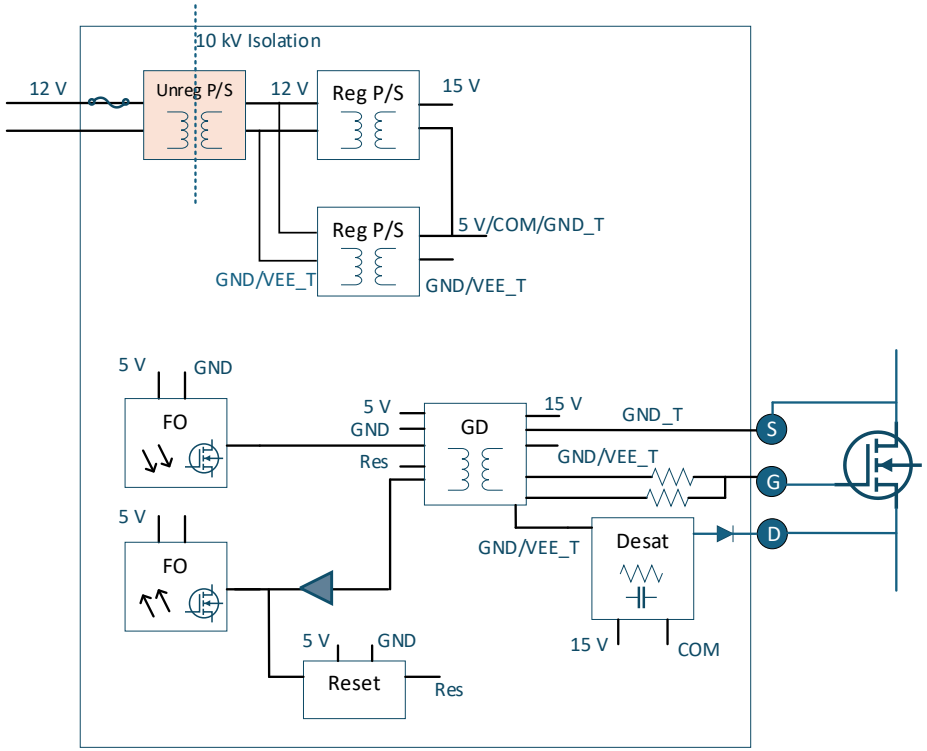
Efficiency v/s power



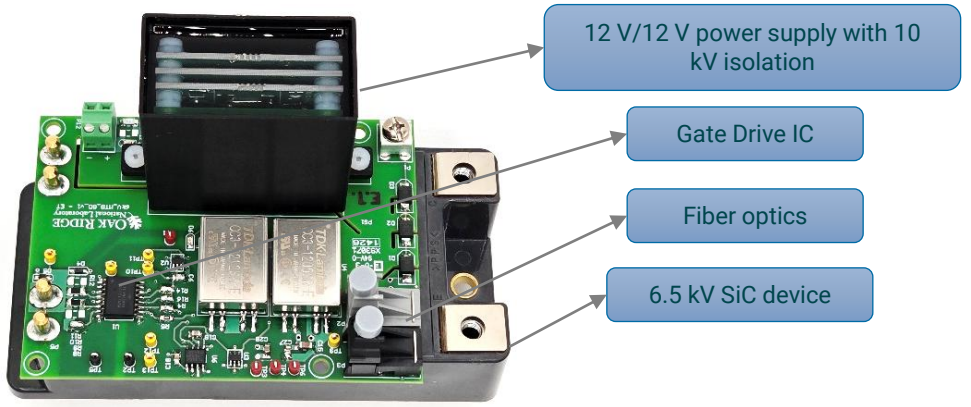
Built and successfully tested a 1:1 12 V PCB based power supply with 10 kV isolation

Integrated 4 kV Class Gate Drive Contd..

Schematic of 4 kV Class Gate Drive with 10 kV Isolated power supply



Hardware implementation of Gate Driver for 6. kV SiC devices



Successfully built and tested a 1:1 12 V PCB based power supply with 10 kV isolation

Device Characterization

- Custom designed 4.0 kV double pulse test circuit for 6.5 kV device.
  - PCB based 4 kV DC link for minimizing parasitic inductance
  - Access for current probes
  - Custom MV inductor

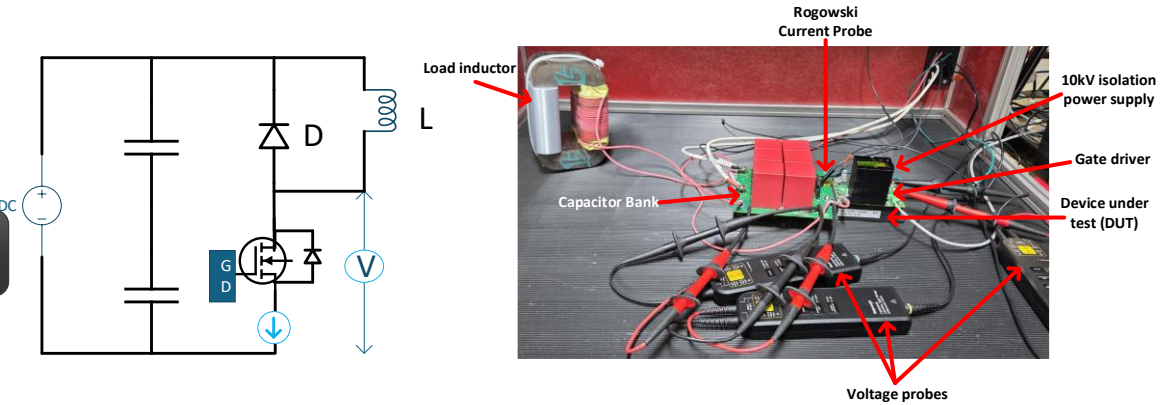
6.5 kV SiC device was characterized at 3.6 kV and 23 A.

Table showing the key parameters of the 6.5 kV SiC device

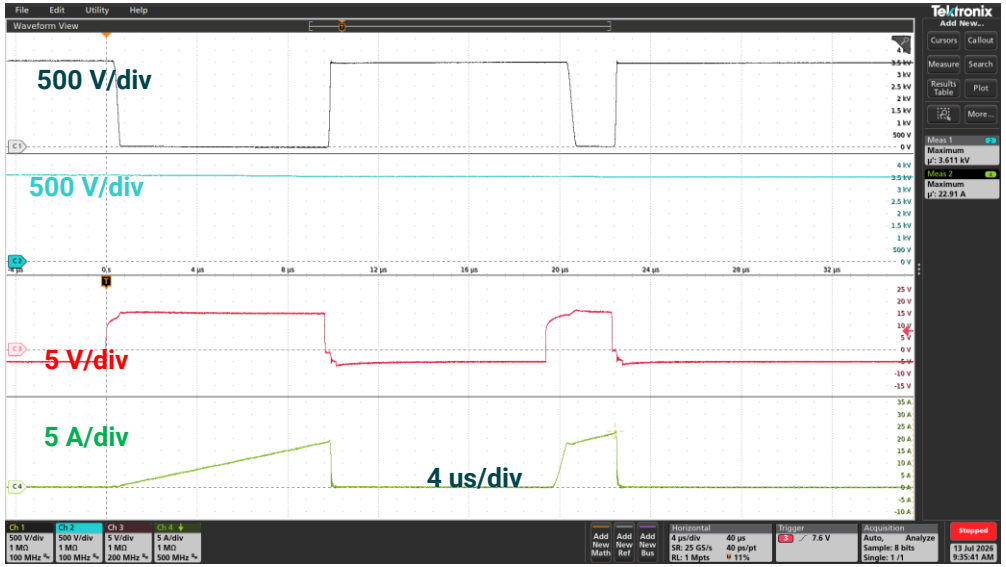
Vds = 3600V, Ids = 20A, Vgs = +15V / -5V, $R_{G(on)} = R_{G(off)} = 7.5\Omega$, Inductive load, L_{load} = 1.6 mH, Tj ~ 23 ºC

Parameter	Symbol	Value	Unit
Turn-on delay time	td(on)	1.13	µs
Rise time	tr	0.28	µs
Turn-on switching energy	Eon	30	mJ
Turn-on dV_{ds}/dt		11.9	V/ns
Turn-on dI_{ds}/dt		0.035	A/ns
Turn-off delay time	td(off)	0.216	µs
Turn-off fall time	tf	0.076	µs
Turn-off switching energy	Eoff	2.97	mJ
Turn-off dV_{ds}/dt		45	V/ns
Turn-off dI_{ds}/dt		0.95	A/ns

Schematic and Image of Double Pulse setup for 6.5 kV SiC device



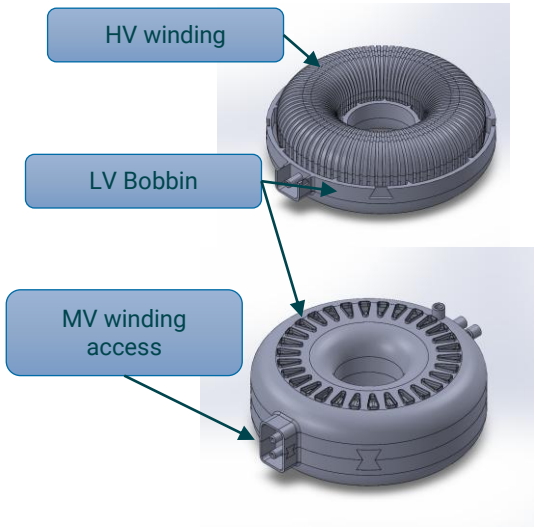
Double Pulse Waveforms at 3.6 kV 23 A



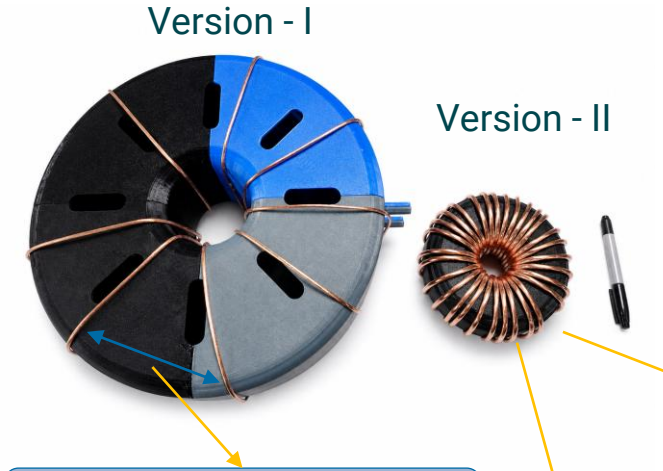
Innovation-III: Core-less Transformer Design

- Toroidal based design for minimizing leakage inductance and electromagnetic interference (EMI)
- Space between LV and HV winding potted using vacuum pressure impregnation for reducing partial discharge
- Modular design to reduce leakage flux

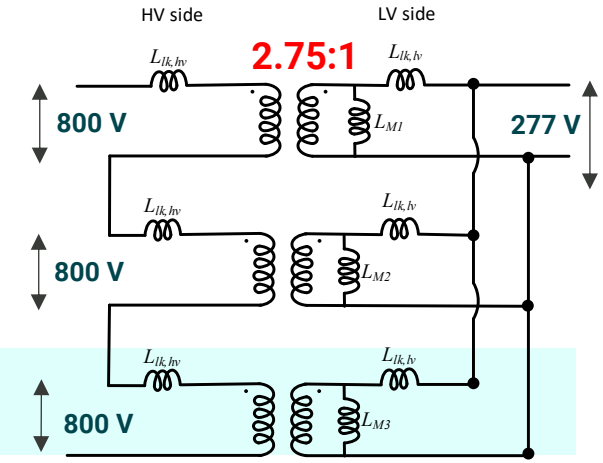
Image of the proposed toroid-based core-less transformer



Prototype 1 v/s Prototype 2.



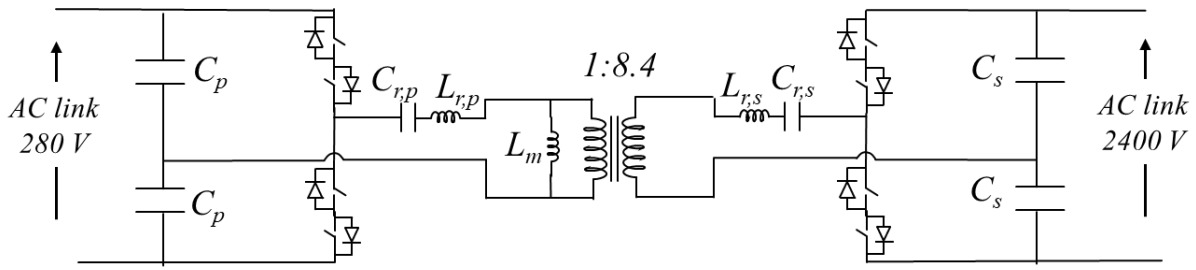
Schematic of modified Coreless transformer



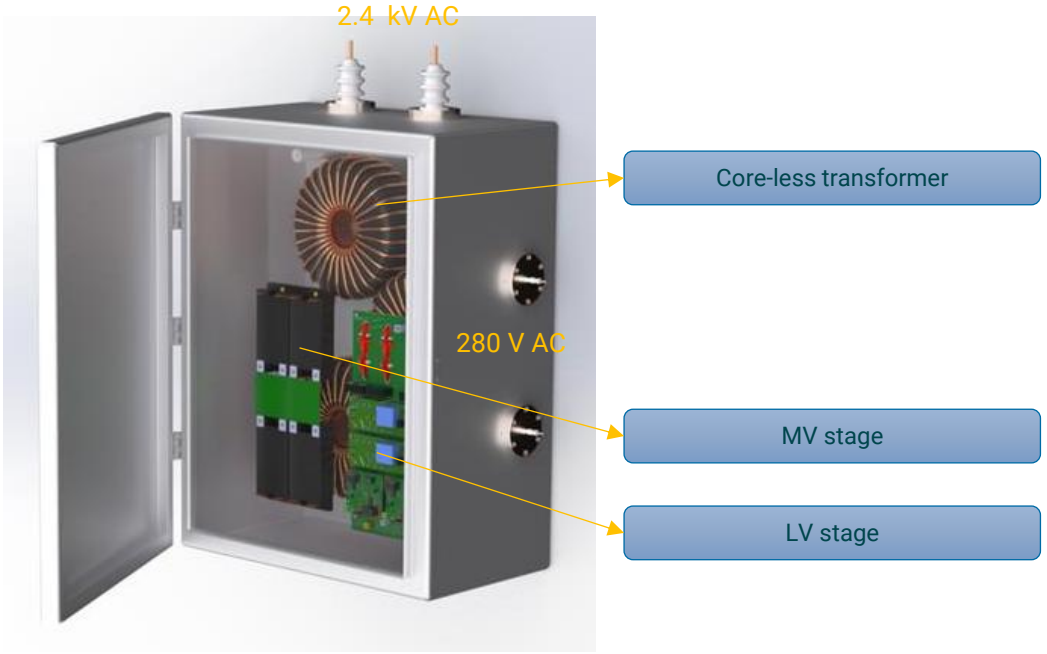
	Target	FEM	Prototype
LV Inductance	15uH	16 uH	18 uH

Transformer design verified through analytical, Finite element method (FEM) and experimental results

Computer-aided Design (Design) of the Prototype



CAD Design of the 2.4 kV/280 V 15 kW Prototype



(18" W x 24" H x 12" D)

Initial CAD design of the converter is completed

Conclusion

- **Topology feasibility established**: Simulation results successfully demonstrate the fundamental operation of the proposed topology and confirm zero-voltage switching (ZVS), supporting its potential for high-efficiency operation.
- **High-voltage technology gap addressed**: Due to the non availability of power supplies capable of MV isolation (>10 kV), an in-house power supply was designed, developed, and integrated with the gate driver. This milestone establishes the capability required for effective 10 kV insulation management.
- **Critical gate-drive capability demonstrated**: A custom gate driver for the state-of-the-art 6.5 kV device was designed, implemented, and successfully demonstrated up to 3.5 kV, establishing a key hardware capability for converter development.
- **High-frequency operation enabled**: The proposed coreless transformer was designed for operation at 100 kHz, supporting a lightweight, and higher-power-density converter implementation.

Impact

- **Supply-chain dependence reduced**: Successful scaling and demonstration of proposed coreless transformer provides an alternative to the conventional transformer, helping address critical supply-chain constraints while reducing system weight and eliminating the core losses.

Future Directions and Next Steps

- **Coreless Transformer Fabrication and Validation:** Fabricate the proposed coreless transformer and validate its insulation performance, including partial-discharge-free operation, at the rated voltage of 2.4 kV.
- **Converter Prototype Development and Integration:** Design and fabricate the low-voltage-side converter printed circuit boards, integrate the converter with the in-house gate driver and coreless transformer, and implement DSP-based PWM control, protection, and monitoring functions.
- **System-Level Experimental Validation:** Test the complete hardware setup to validate power-transfer capability, input and output voltage regulation, and zero-voltage-switching (ZVS) performance under the targeted operating conditions.

Acknowledgements

This material is based upon work supported by the U.S. Department of Energy, Office of Electricity (OE)

References

[1] Piotr Czyz, et'al. "Design and Experimental Analysis of 166 kW Medium-Voltage Medium-Frequency Air-Core Transformer for 1:1-DCX Applications " IEEE Journal Of Emerging And Selected Topics In Power Electronics, Vol. 10, No. 4, August 2022