Self-Oscillating WBG-based VHF Power Conversion for FREEDM Applications

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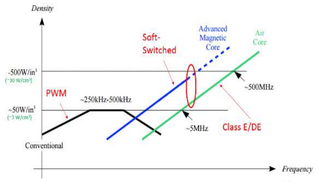
Overview

System electrification requires power supplies that are:

- >99.99% efficient
- Contribute the least to system volume and weight (i.e. high power density)
- Make up the lowest percentage of system cost
- Without a doubt reliable

Switching frequencies entering the VHF range (>30MHz)

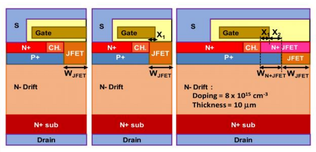
- Confluence of HF-FOM WBG devices, ZVS self-oscillating power circuits, advanced package technology



Estimate of DC-DC converter power density versus f_{sw} [5]

SiC-MOSFET Structure (V_{rating} = 1.2kV)	HF-FOM (mΩ-nC)
Conventional ◄	2006
CPM2-1200-0080B ╪	1840
Central-Implant ╪	1390
Split-Gate ◄	1287
Buffered-Gate (Low JFET region doping) ◄	596
Buffered-Gate (High JFET region doping) ◄	503

◄ - NCSU
╪ - CREE/Wolfspeed



Cross-sectional views of fabricated 1.2 kV SiC Accu-channel C-MOSFET, SG-MOSFET, and BG-MOSFET structures. All the structures have the same channel length (0.5µm), W_{JFET} (0.7µm), and JFET doping concentration ($3\times10^{16}cm^{-3}$) [34]

Alignment with FREEDM mission

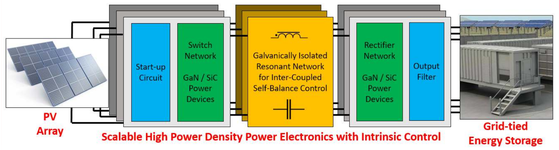
- Front-end DC-DC converter applications for Smart-Grid (PV, energy storage, data centers, transportation, space, etc.)

Power Conversion System Specification	
Input DC Voltage (V)	800 V
Output DC Voltage (V)	48 V
Switching Frequency (Hz)	> 500,000 Hz
Output Power (W)	1200 W
Efficiency (%)	> 95%

Method

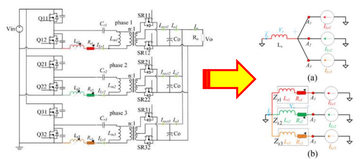
Grid modernization through innovation

- Simplistic ZVS self-oscillating power circuit topology incorporating WBG devices (GaN, SiC) enhances reliability and lowers overall system cost by eliminating external gate drive circuit



- Resonant converter topologies naturally facilitate high frequency self-oscillation by tapping into resonant tank energy
- LLC resonant converter integrates circuit parasitics into its resonant components

- Enables plug-n-plug power electronics for interfacing renewables and energy storage with “N+1” redundancy and self-balancing load sharing via passive impedance matching (PIM) across inter-coupled resonant tanks [35]-[36]



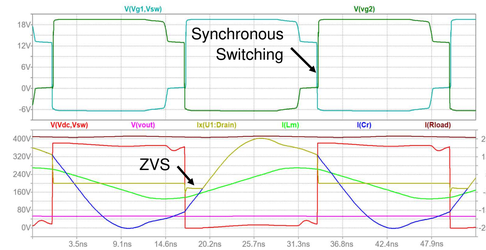
Equivalent common-inductor three-phase LLC resonant converter. Transformations from (a) common inductor to (b) equivalent circuit [29]

- PIM minimizes inductor and capacitor component mismatch due to aging, temperature, and tolerances [37]

Results

Achievements

- Simulation of 1.2kW self-oscillating LLC resonant converter



- Improved efficiency by eliminating external gate driver circuit losses

$$P_{cond,MOSFET} = {I_{rms}}^2 R_{on} = (13A)^2(65m\Omega) = 10.99W$$

$$P_{sw,MOSFET} = P_{sw,on} + P_{sw,off} = 0W + \left({}^{0.18\mu J}/_{0.033\mu s}\right) = 5.45W$$

$$P_{rectifier} = V_f I_{rms} = (0.7V)(25A) = 17.50W$$

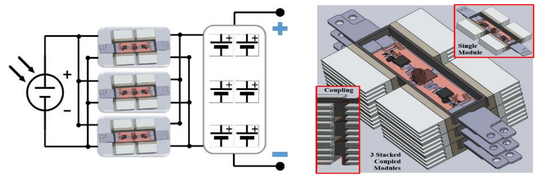
$$P_{total} = 2\times\left(P_{cond,MOSFET} + P_{sw,MOSFET}\right) + 2\times\left(P_{rectifier}\right) = 67.88W$$

$$\eta_{self-osc.} = \left(1 - {}^{67.88W}/_{1200W}\right)\times 100\% = 94.34\%$$

$$P_{gate\ driver} = C_{iss}{V_{gs}}^2 f_{sw} = (660pF)(20V)^2(30MHz) = 7.92W$$

$$\eta_{conventional} = \left(1 - \frac{(67.88W + 2\times 7.92W)}{1200W}\right)\times 100\% = 93.02\%$$

- Concept for 3 stacked, load sharing PIM inter-coupled power modules



Future Work

- Finalize electro-physical layout and multi-physics simulation of self-oscillating VHF converter
- Fabricate and test individual and inter-coupled power conversion systems
- Extend concept to full-bridge and synchronous rectifier circuits
- Study VHF switching of WBG devices

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