# Solid State Transformer For Power Distribution Applications

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### **Electric Distribution Transformer**



#### ■ Advantages

- Highly robust / Reliable
- Highly efficient (98.5% 99.5%)
- Relatively inexpensive



#### ■ Weaknesses

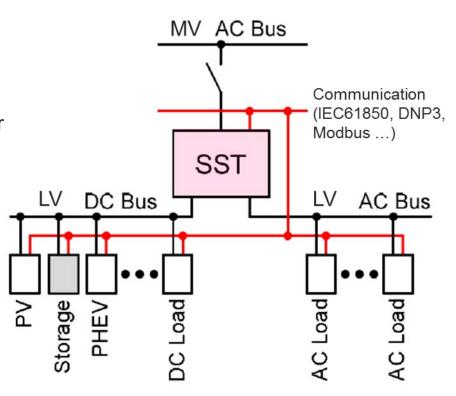
- No capability of voltage/ frequency regulation
  - Coupled harmonics and other disturbances
  - Difficult to control power flow
- No DC port
  - Not friendly for integration of renewables, EV and energy storage
- Large Weight / Volume



### Solid State Transformer: Key Enabler for Internet of Energy



- □ DC and/or AC interfaces with high frequency isolation between medium voltage grid and renewables, distributed energy storage, EV, and DC or AC loads
- ☐ A platform enables uni- or bi-directional power flow with local autonomous control and / or distributed intelligence through communications
  - Fault management
    - Current limiting
    - Disconnect/reconnect
  - •Power Management:
    - Control power flow and power factor
    - Change/Control customer voltage
    - Provide DC power
    - Eliminate harmonics
    - Low voltage ride through
    - Support islanding mode
  - Energy Management
    - Monitor energy usage
    - Control/dispatch power
    - Demand side management



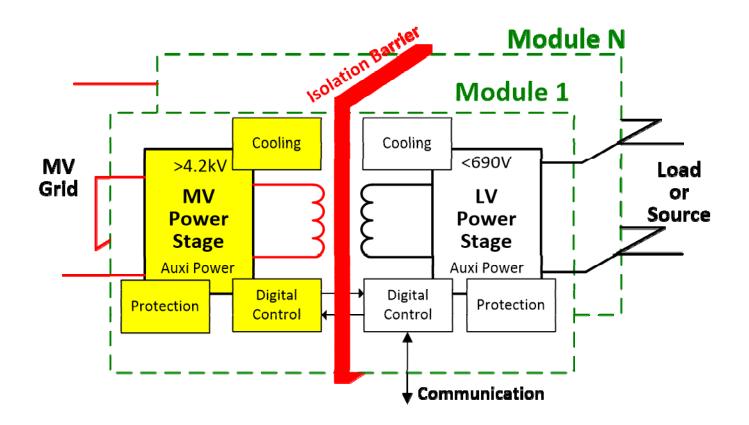


### **Technology Challenges of SST**



- ☐ High efficiency topology
- Modularized design
- ☐ Control & communication
- Voltage/current balancing

- ☐ High voltage isolation
- ☐ Reliability & Redundancy
- ☐ Protection & Grounding
- □ Packing & cooling



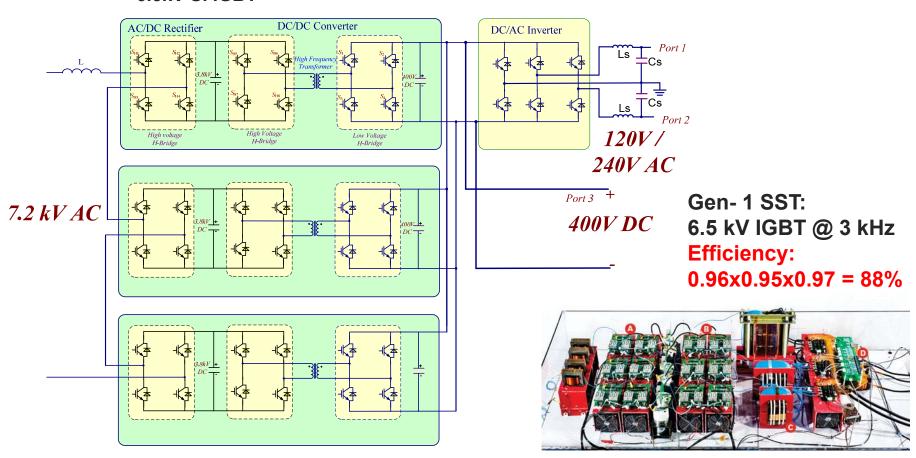


### **Critical Challenge of SST: System Efficiency**



### ☐ Gen-I SST, 2008-2011, 3.6 kV/10 kVA, system efficiency: 88%

#### 6.5kV Si IGBT





### **Critical Challenge of SST:** SYSTEMS CENTER High Voltage Isolation with High Power Density

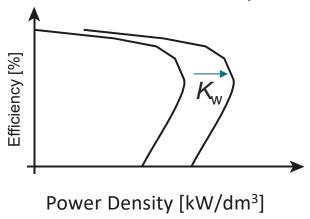


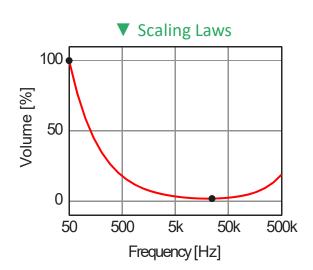
- ☐ Better window area utilization of magnetic core
  - Increased power density
  - **Increased efficiency**
- ☐ How to realize high voltage isolation and better window area utilization is a critical challenge

Transformers: Scaling Laws

$$A_{\text{Wdg}}A_{\text{Core}} = \frac{\sqrt{2}}{\pi} \frac{P}{k_{\text{w}} J_{\text{RMS}} B_{\text{p}} f}$$

$$V \propto (A_{
m Wdg} A_{
m Core})^{rac{3}{4}} \propto rac{1}{f^{rac{3}{4}}}$$







## Combining Wireless Power Transfer with High Efficiency for MV Transformer

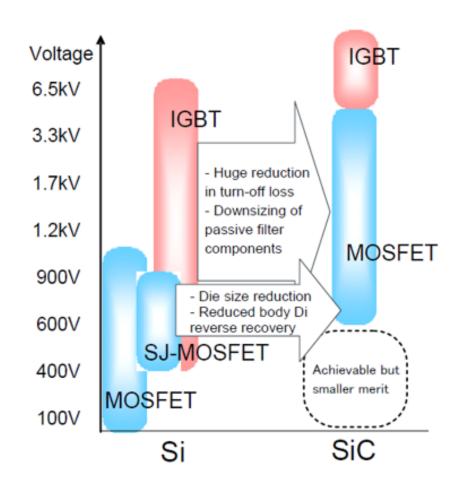


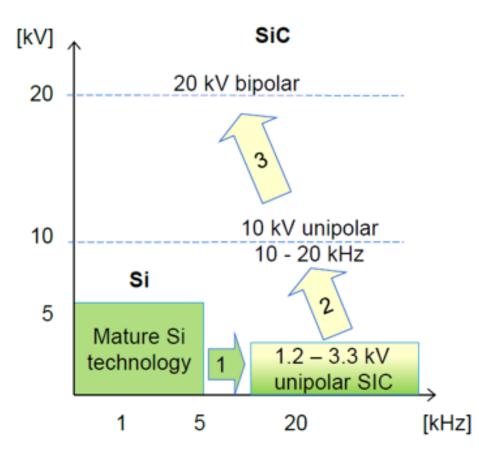
☐ High voltage isolation (for example, 50 kV basic insulation level) between LV-side and MV-side is required for all MV power transformers in SST
 ☐ This innovative technology significantly improves the state of the art in how to achieve the high-voltage isolation and greatly simplify the manufacturing process
 ☐ From isolation point of view, it can achieve 100kV basic insulation level similar to that of wireless power transfer
 ☐ From energy efficiency point view, it demonstrated >99.5% transformer efficiency at 40kHz operation frequency thanks to better window area utilization of magnetic core while eliminating EMI issue



### Advantages of HV WBG Power Devices







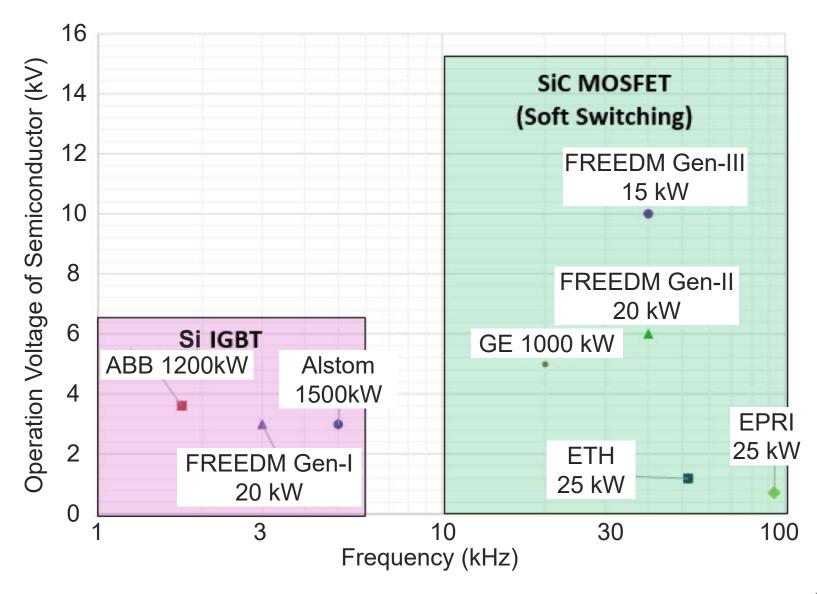
Reference: Rohm website

Reference: Peter K. Steimer, ABB, MV WBG Power Electronics for Advanced Distribution Grids, NIST/DOE Workshop, April 15, 2016



### Why HV SiC with Soft-Switching



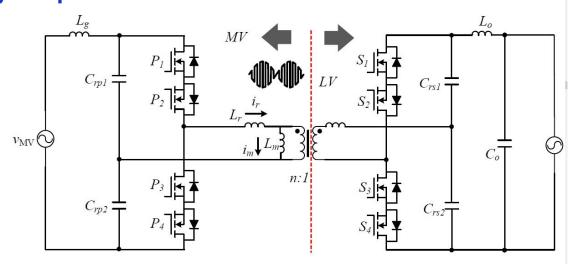


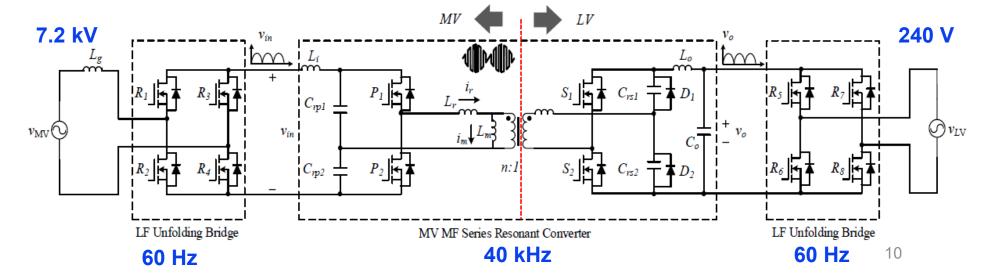


## **Direct AC-AC Converter** with 15 kV SiC MOSFETs



☐ We use direct AC-AC converter with 15 kV SiC MOSFETs, which makes the system very simple and reliable

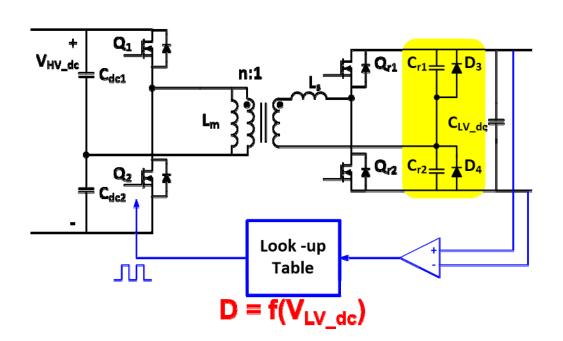


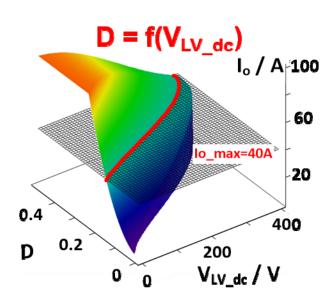




### **Hybrid Resonance with DAB converter**





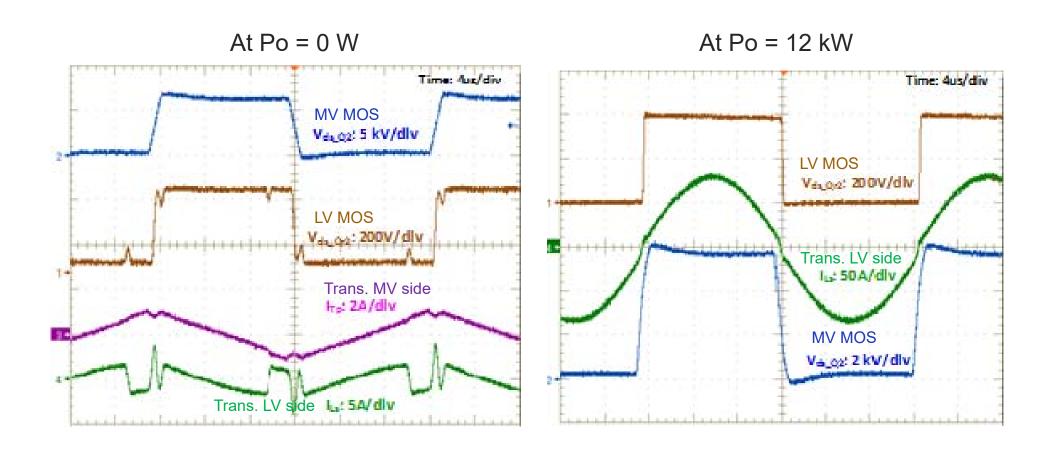


- Soft switching from zero to full load
- Keeps the high efficiency characteristic of resonant converter
- No current sensor needed, duty cycle only related to the low-side voltage
- Seamlessly realize soft startup, normal ZVZCS operating, over-current limiting, short-circuit fault protection and fault auto-recovery



## **Zero-Voltage Soft-Switching from No-Load to Full Load**



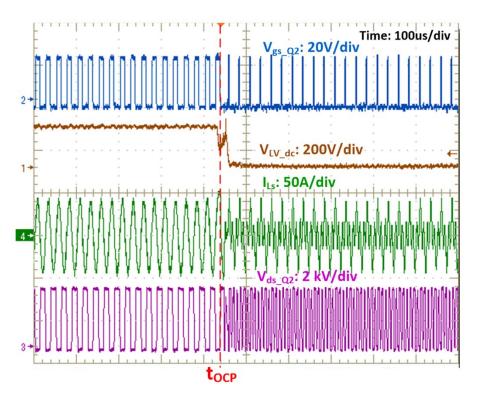




## **Short-Circuit Protection** without Current Sensor

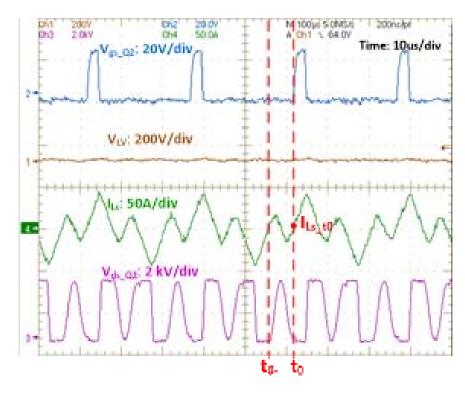


- □ Experimental waveforms of short circuit protection demonstrated a 25 µs over-load protection speed while no need of the current sensor
  - Time scale: 100µs/div



Low-side voltage from 200V to 0V

Time scale: 10µs/div

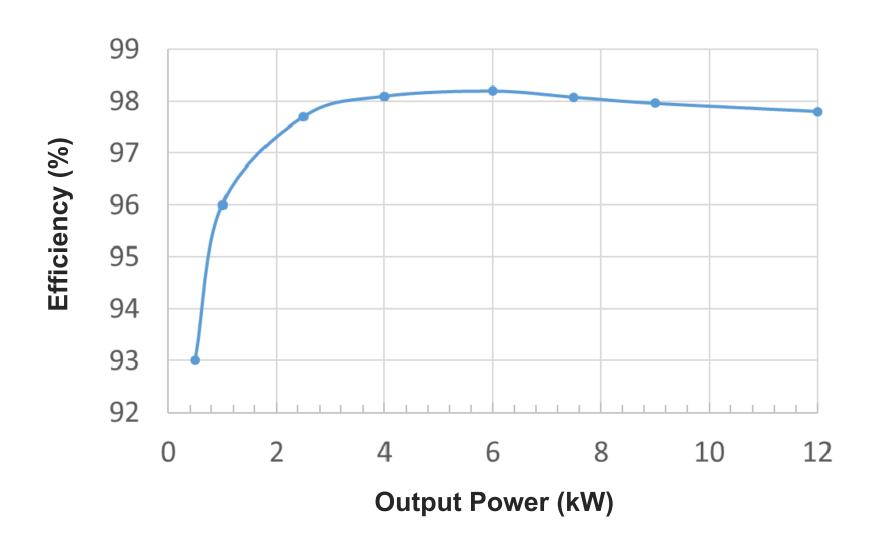


Low-side voltage =0V



## System Efficiency of Direct AC-AC SST







### Critical R & D Needs of SST



- ✓ Topologies and control methods that combine multiple functions (e.g. grid current control and voltage step-down) into one single topology
- ✓ EMI free MV soft-switching technologies (zero-voltage and/or zerocurrent) with minimum switching losses for MV or HV applications
- ✓ Power-over-fiber based gate drive with comprehensive protection functions for HV SiC power devices with > 20 kV isolation
- √ High efficiency transformer with medium or high frequency and > 20 kV high voltage isolation using improved dielectric and magnetic materials

#### **NC STATE UNIVERSITY**

