FREEDM SYSTEMS CENTER

Wide Band-Gap Devices for Solid State Transformer Applications

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Outline

- **Challenges of Solid State Transformer**
  - Concept of Solid State Transformer
  - System Requirements of Solid State Transformer
- **Opportunities of WBG Devices for SST Applications**
  - Advantages of WBG devices
  - Early adoption of WBG devices for SST

Electrical Transformer

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

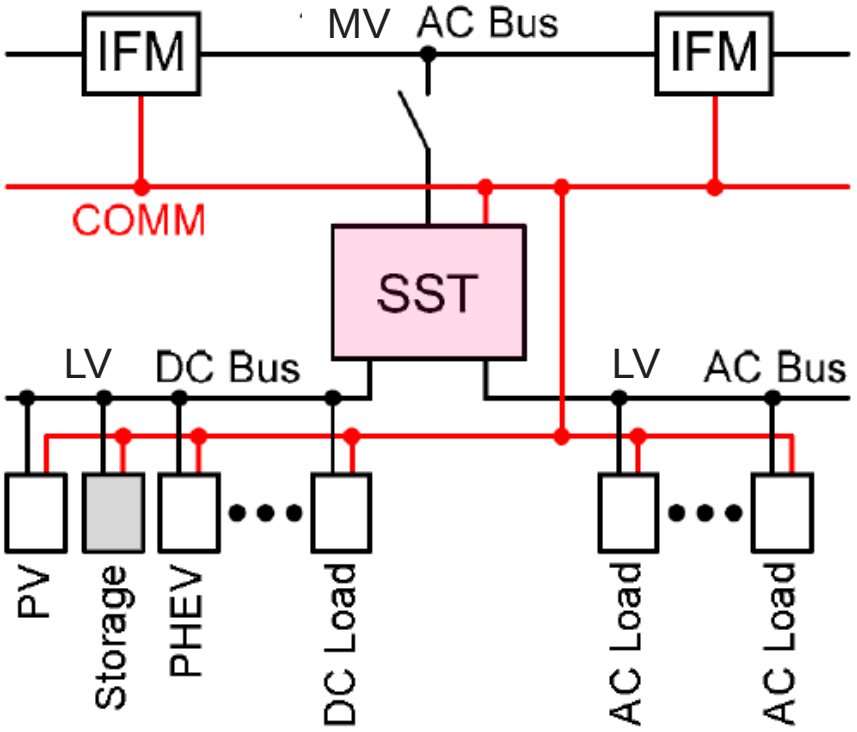
- **Weaknesses**
  - No capability of voltage/ frequency regulation
  - Large Weight / Volume

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

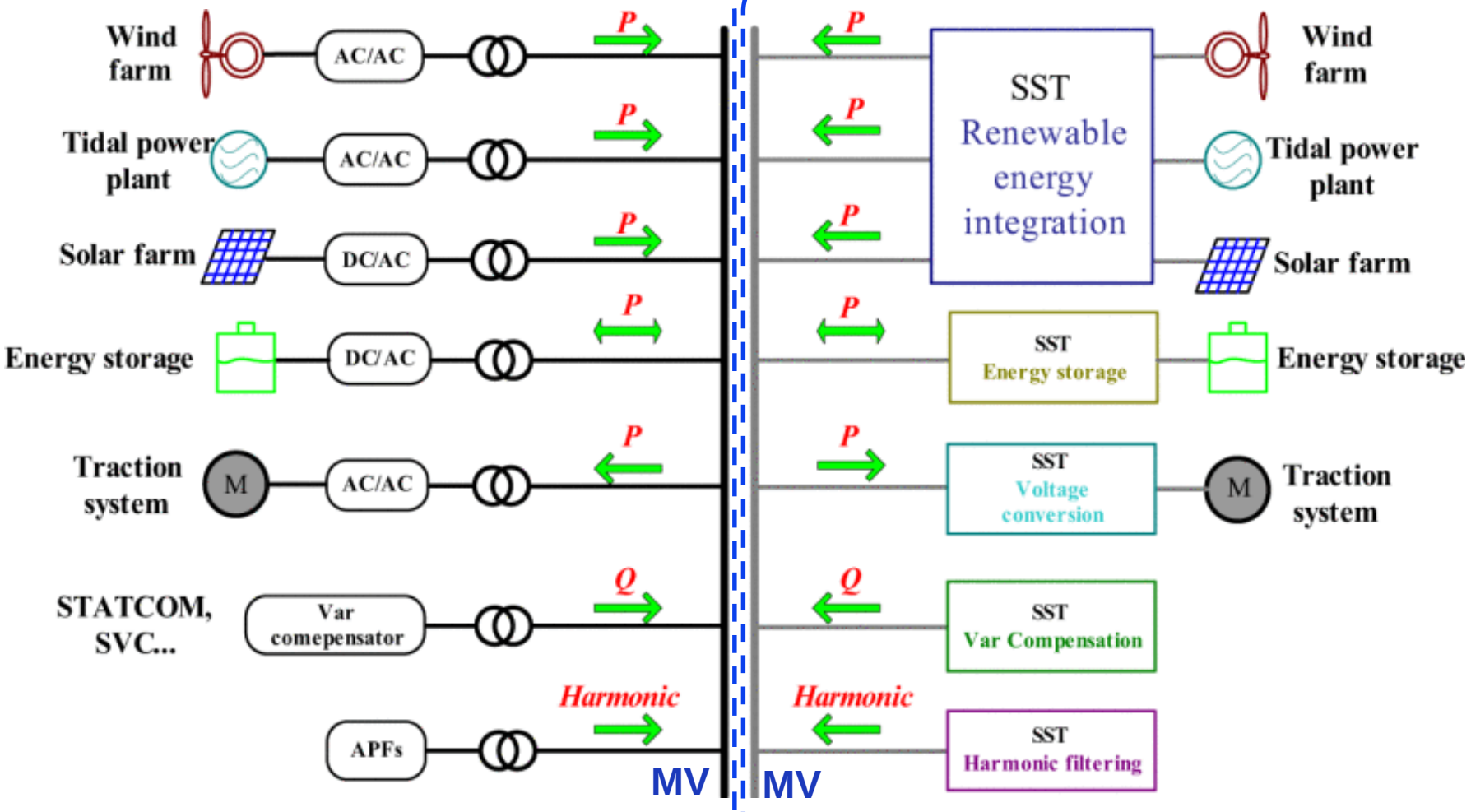
- DC and/or AC interfaces with high frequency isolation between medium voltage grid and Renewable Energy Resources, Distributed Energy Storage, Electric Vehicles, and DC or AC loads
- A platform enables uni- or bi-directional power flow with Local Autonomous Control and Distributed Intelligence through Communications

SST: Solid State Transformer

IFM: Intelligence fault managemer



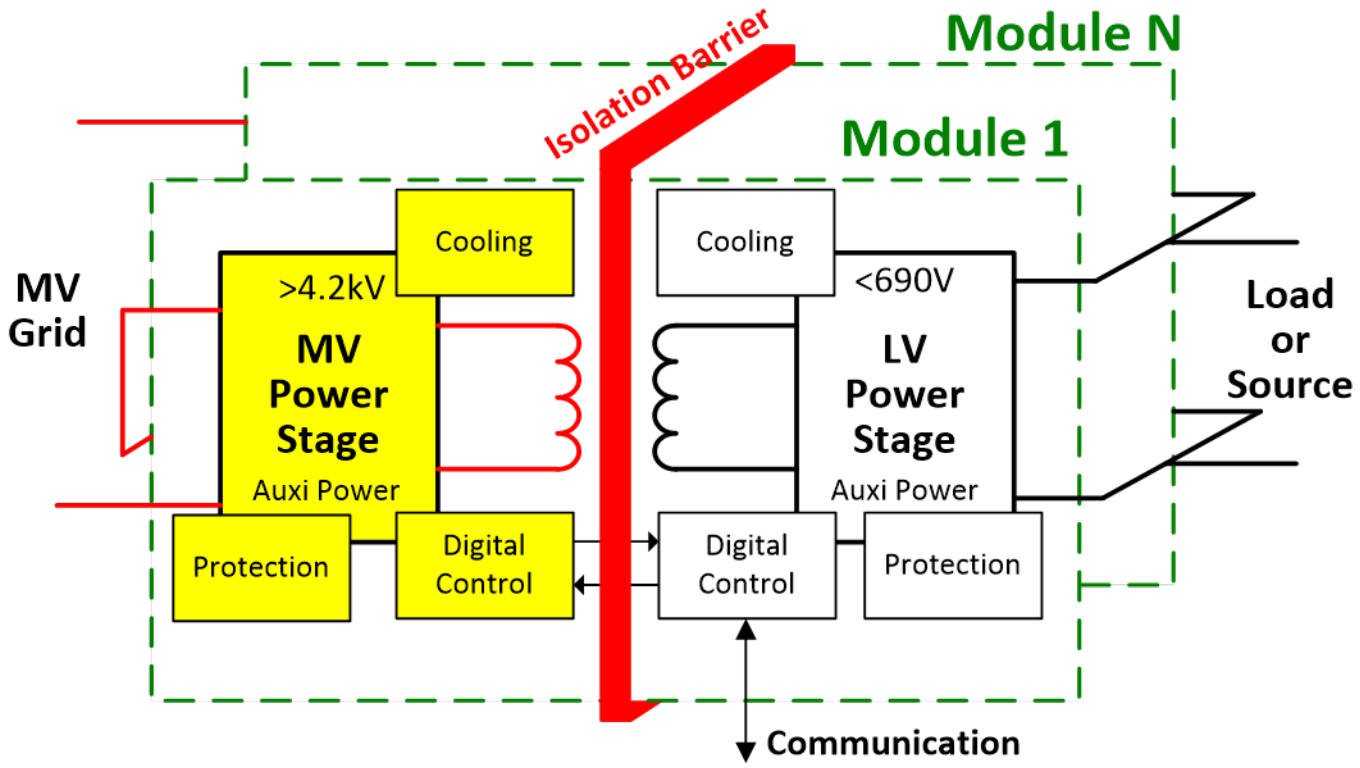
Potential Applications of SST in Future Distribution System



Reference: Xu, She, etc, Review of Solid-State Transformer Technologies and Their Application in Power Distribution Systems

Key Technology Challenges of SST

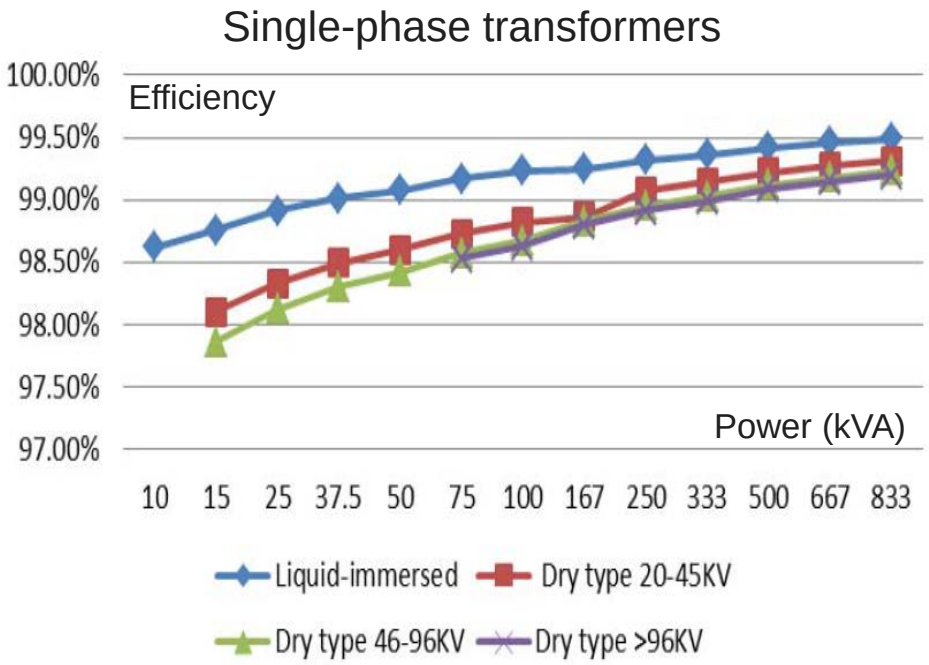
- Modularized design
- Voltage/current balancing
- High efficiency topology
- Packing & cooling
- Control & communication
- Redundancy & reliability
- High voltage isolation
- Grounding & protection

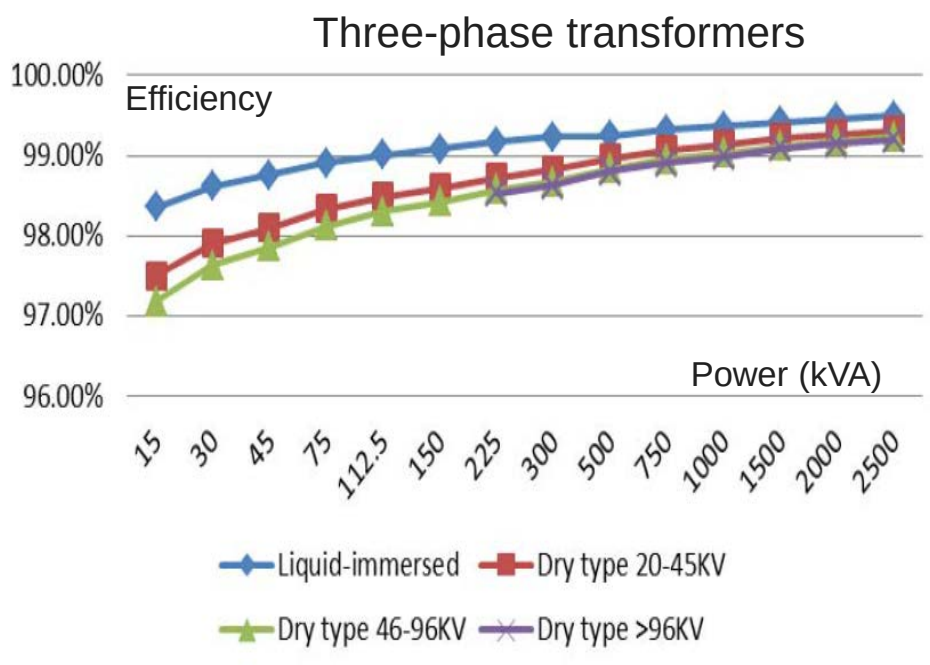


Efficiency Challenge of SST System

- The overall efficiency of the distribution transformer required by the standard is >97% irrespective of power rating
- Big **efficiency challenge** for MV and LV power stage plus isolation in the SST

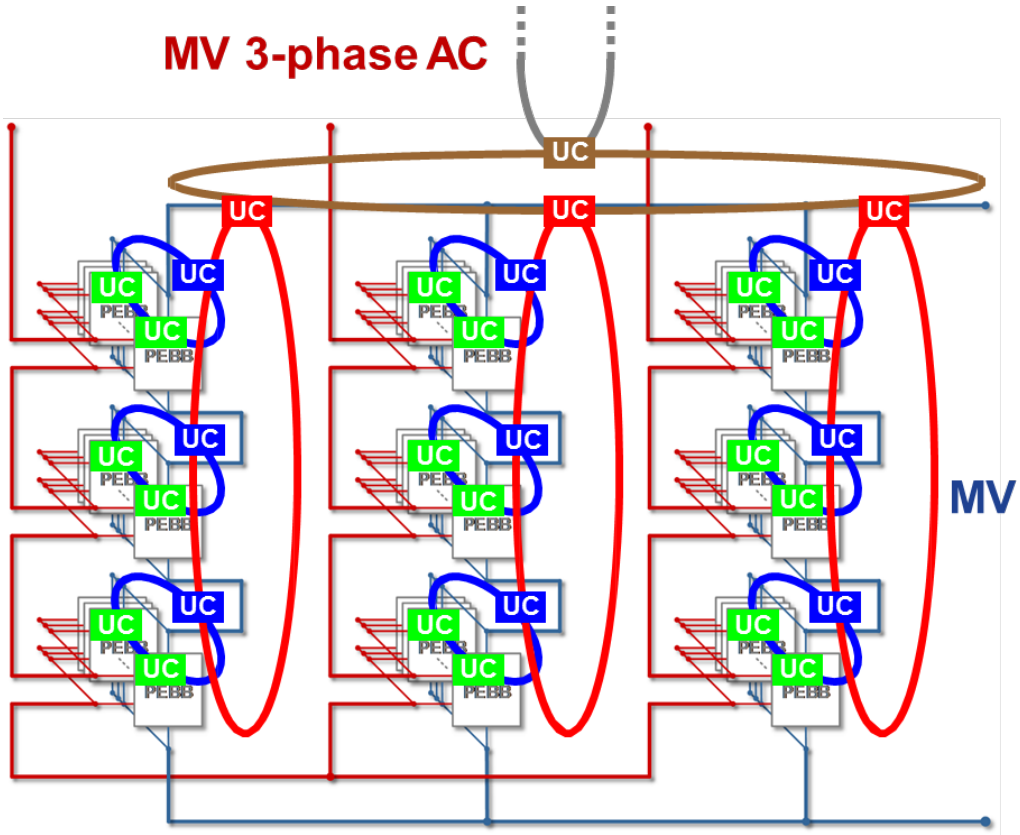
Distribution transformer national efficiency standards of U.S.A





Control Challenge of SST System

❑ **Distributed Hierarchical Control**



Scalable PEBB-based converter

- Mission Control
- Converter Control
  - Multi-phase coordination
  - Application specific control
- **Stacking Control**
  - Voltage balancing
  - Output voltage / current control
- **Paralleling Control**
  - Current balancing
- **PEBB Control**
  - Gate signal generation
  - Local high frequency control (> f_{sw})
  - Fast local protection

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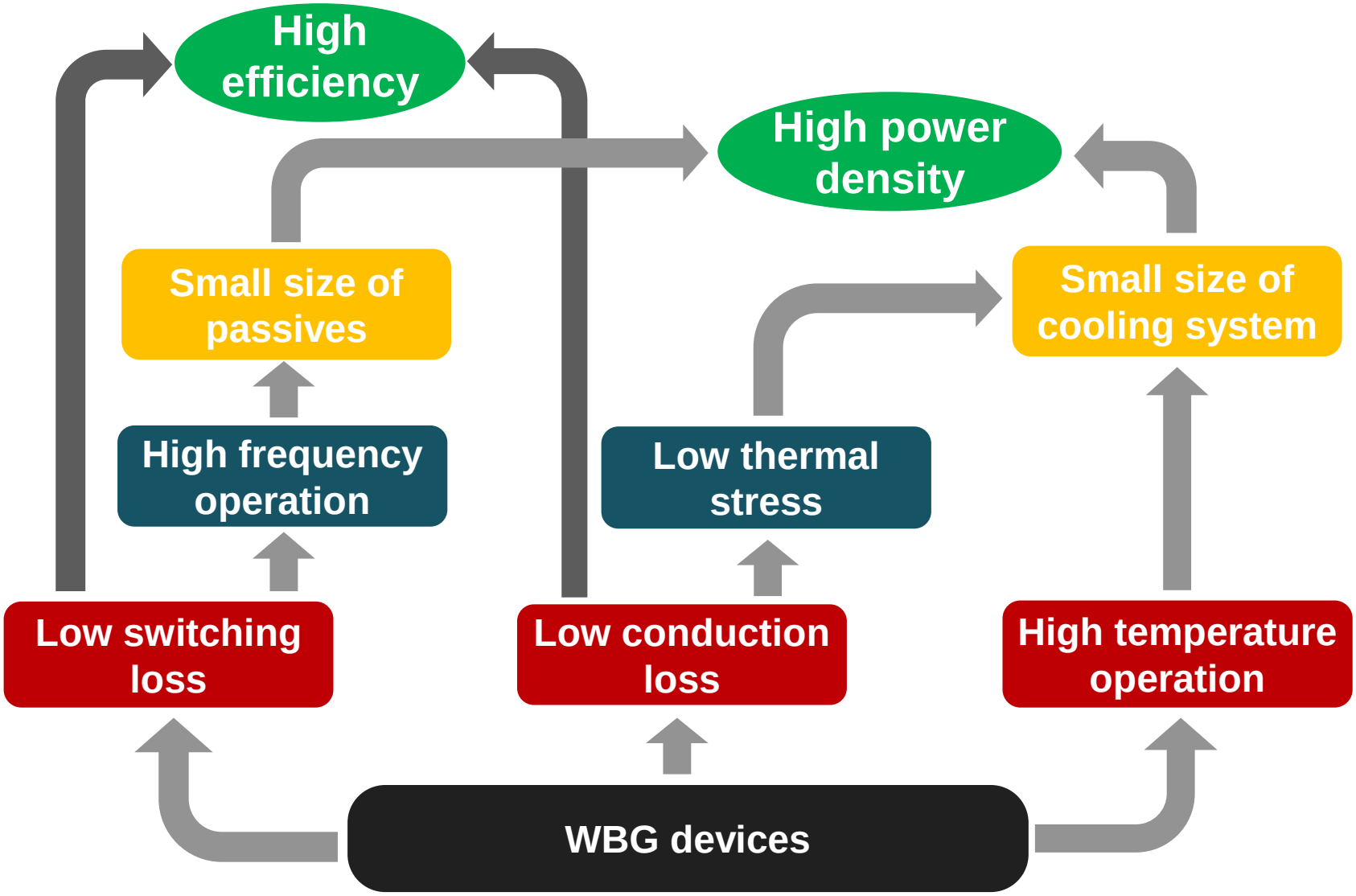
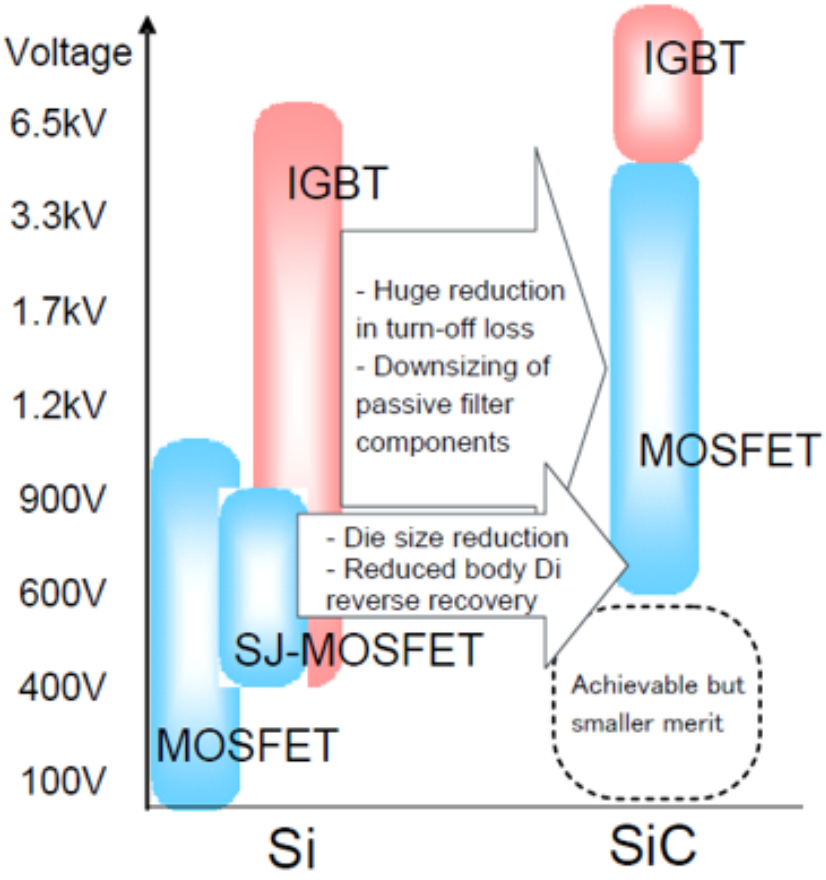
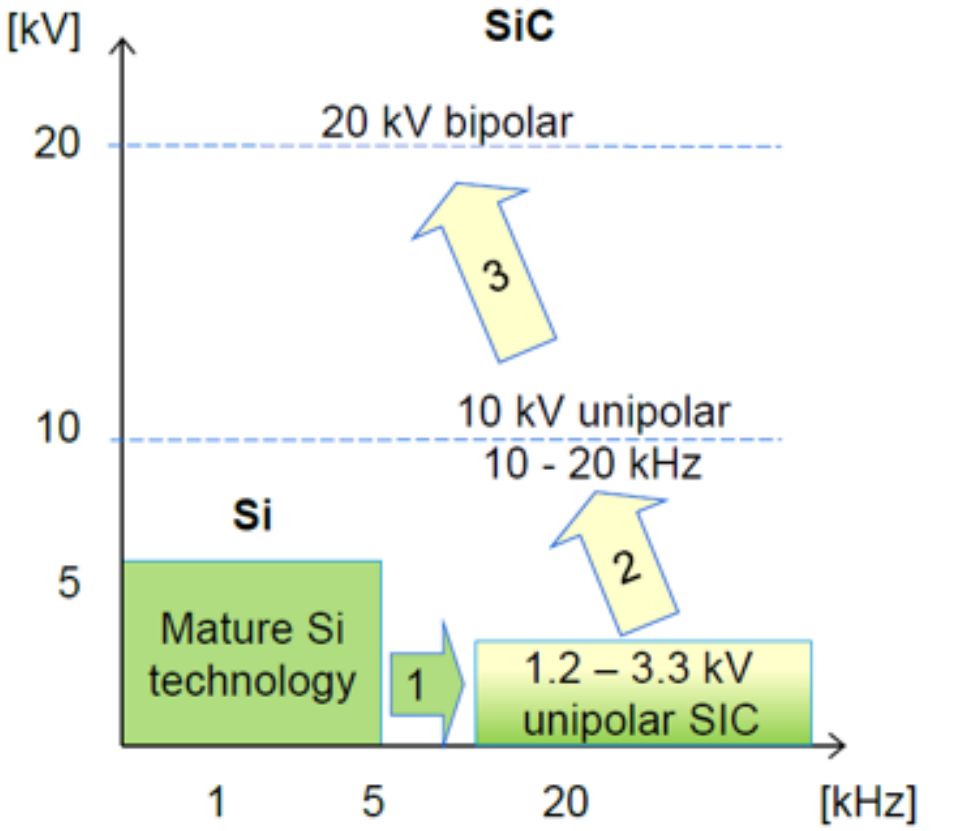
Why WBG Semiconductors ?



Advantages of HV WBG Power Devices

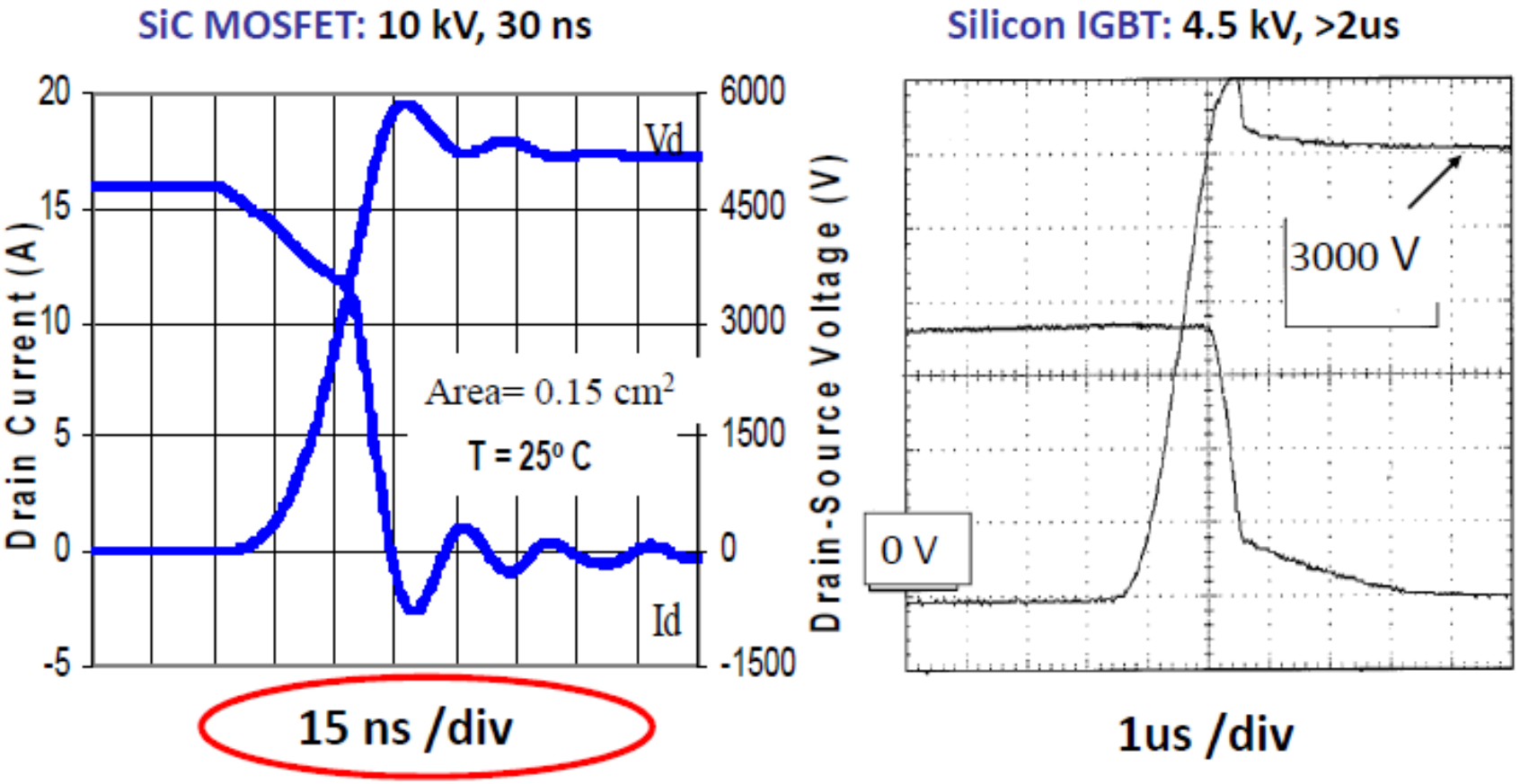


Reference: Rohm website



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

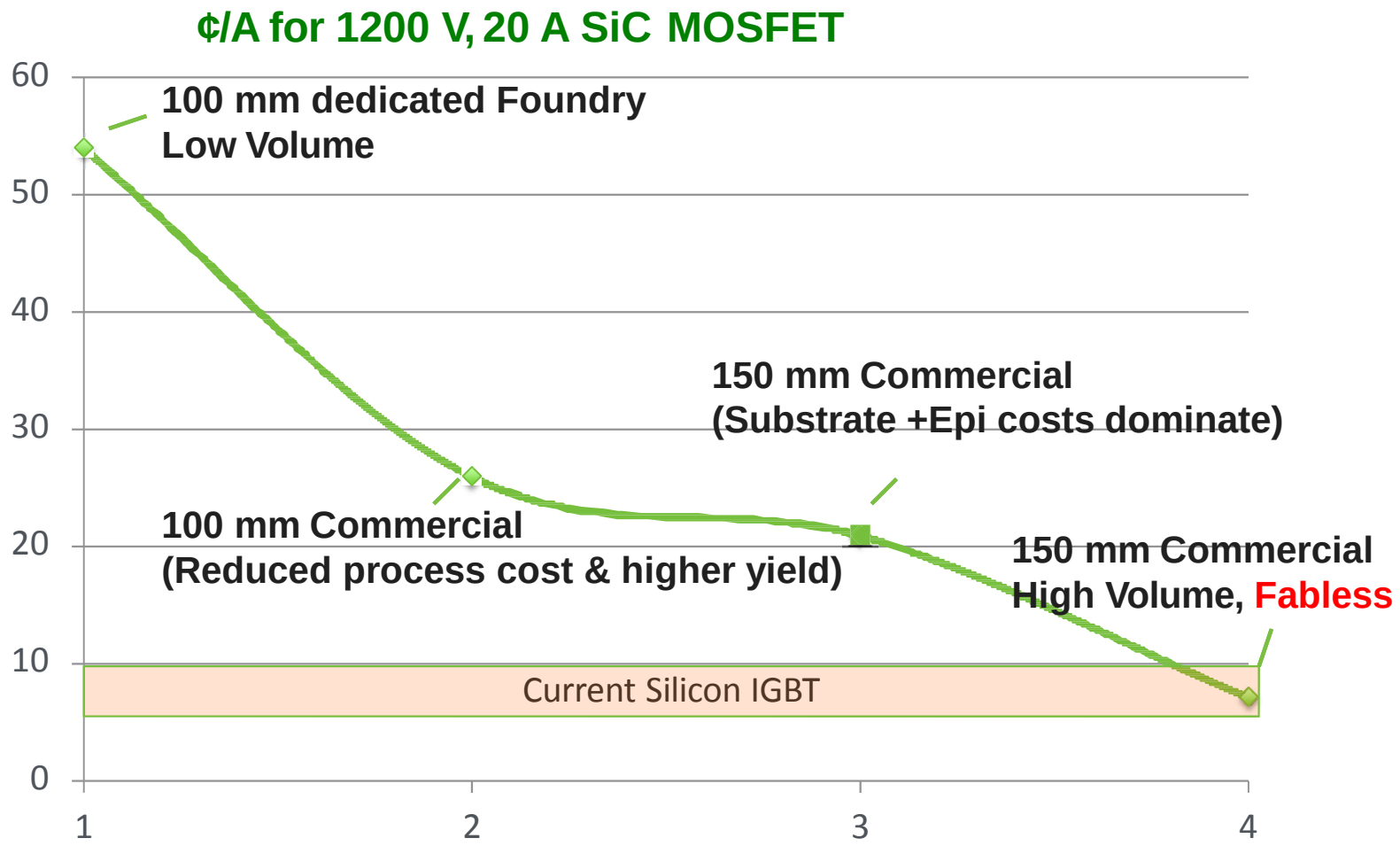
High Switching Speed at High Voltage of SiC MOSFET



A. Hefner, et.al. “Recent Advances in High-Voltage, High-Frequency Silicon-Carbide Power Devices,” IEEE IAS Annual Meeting, October 2006

WBG Devices Will be Competitive with Silicon

- Price of SiC switches will be at ~10 Cents/Amp possibly in 3-4 years



Reference: Anant Agarwal, Wide Bandgap Device Manufacturing, NIST/DOE Workshop, April 15, 2016

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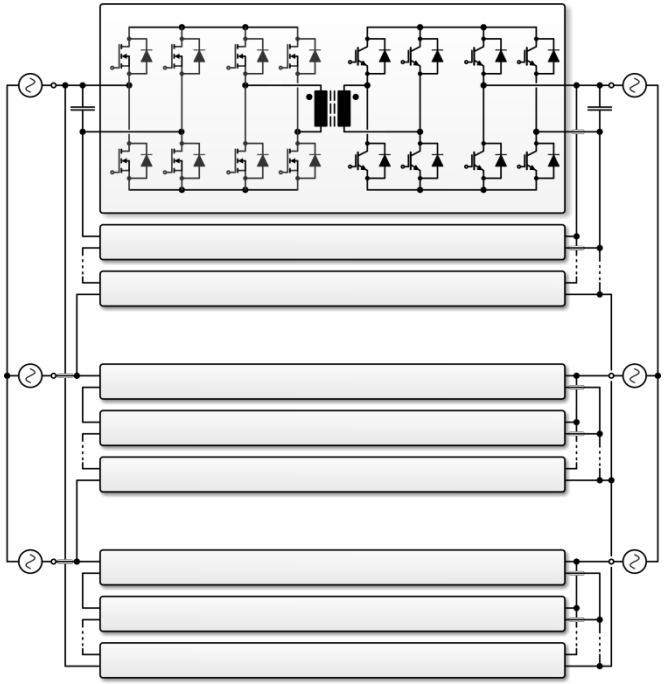
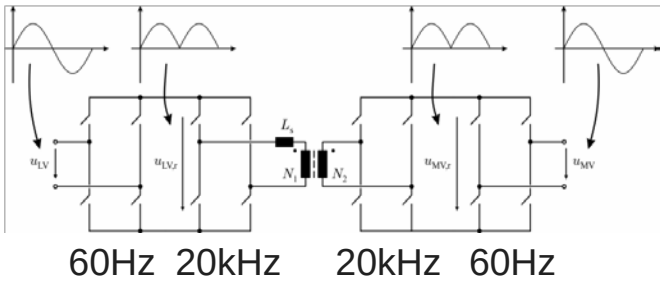
AC/AC SST Using 13kV SiC Mosfets for Power Substation

- **Key technologies**
  - ✓ **Power device:** 13kV, 120A SiC half-bridge MOSFET modules
  - ✓ **Single-stage AC-AC topology**: Only one-stage operates at 20kHz MF to control the voltage
- **Comparison between this SST solution and the conventional 50/60 Hz transformer**
  - ✓ Potential smart grid application because of the voltage controllability
  - ✓ 1.3X weight reduction and 2X volume reduction with 97% total efficiency

3phase,13.8kV$_{l\text{-}l}$,1MVA

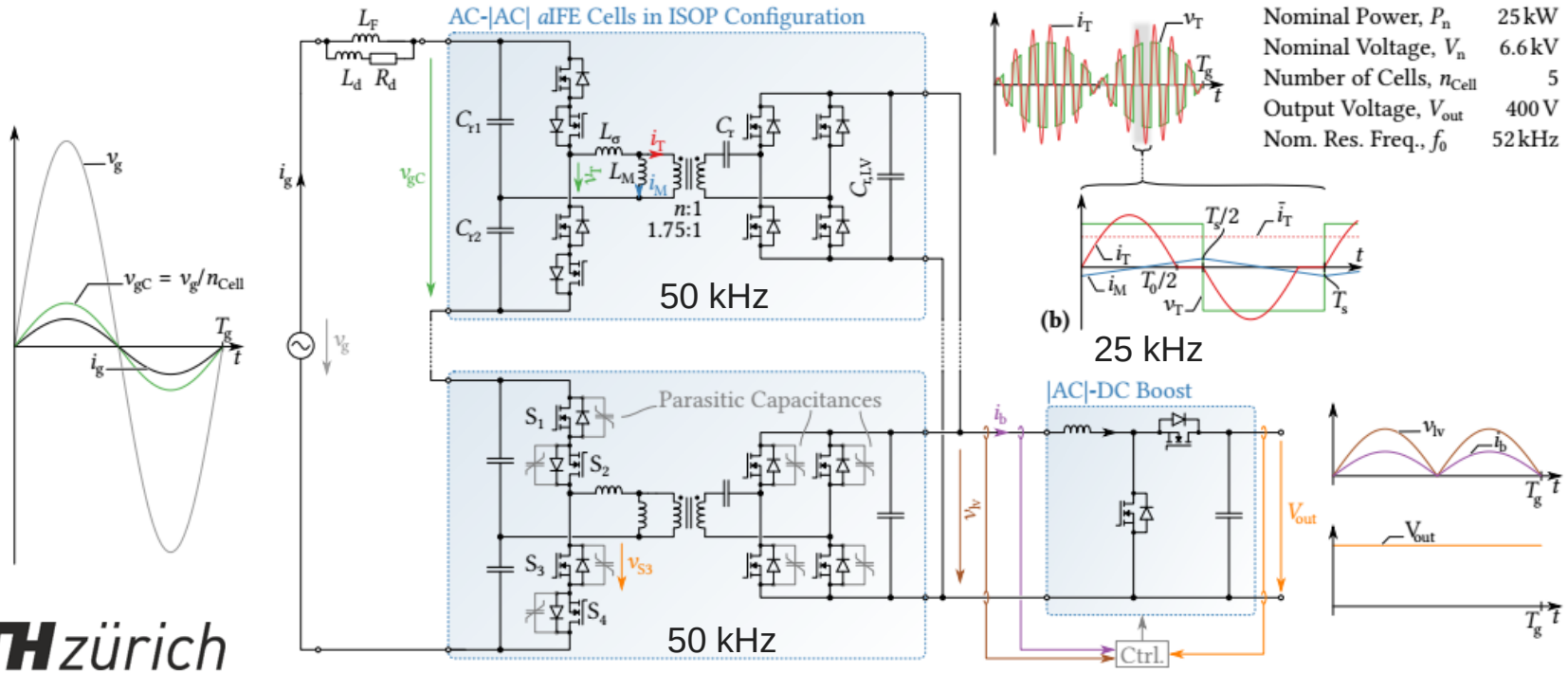




M. K. Das, C. Capell, D. E. Grider, S. Leslie, J. Ostop, R. Raju, M. Schutten, J. Nasadoski, and A. Hefner, "13kV, 120A SiC half H-bridge power MOSFET modules suitable for high frequency, medium voltage applications," in Proc. IEEE ECCE, Sept. 2011.

AC/DC SST Using 1.7kV SiC for Data Center: Boost Power Stage on LV Side

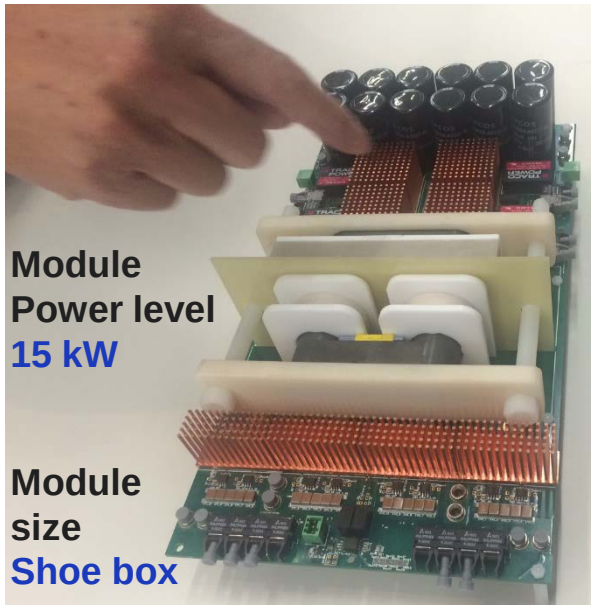
- **Key technologies**
  - ✓ **Power device:** 1700V/45mOhm SiC MOSFET, 5 cells in series for MV; 900V/11.5mOhm SiC for LV
  - ✓ **Topology**: LLC resonant AC-DC with fixed gain + LV boost dc-dc
  - ✓ **The simplest high-voltage-side topology and the simplest system-level control**
- **Comparison between this SST solution and the conventional 50/60 Hz transformer + LV PFC converter**
  - ✓ 1-2% efficiency improvement and significant size/weight reduction

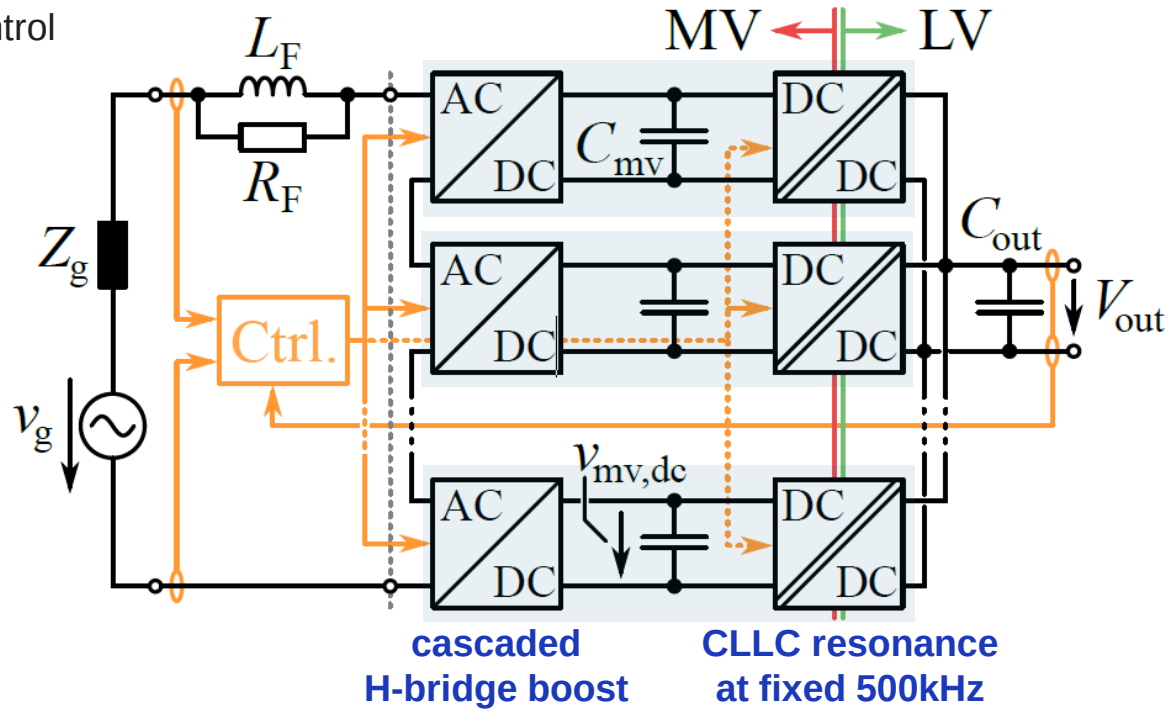


J. E. Huber, D. Rothmund, L. Wang, and J. W. Kolar, "Full-ZVS modulation for all-SiC ISOP-type isolated front end (IFE) solid-state transformer," in Proc. IEEE ECCE, Sep. 2016.

AC/DC SST Using 1.2 kV SiC & 650V GaN for Data Center: Boost Power Stage on MV Side

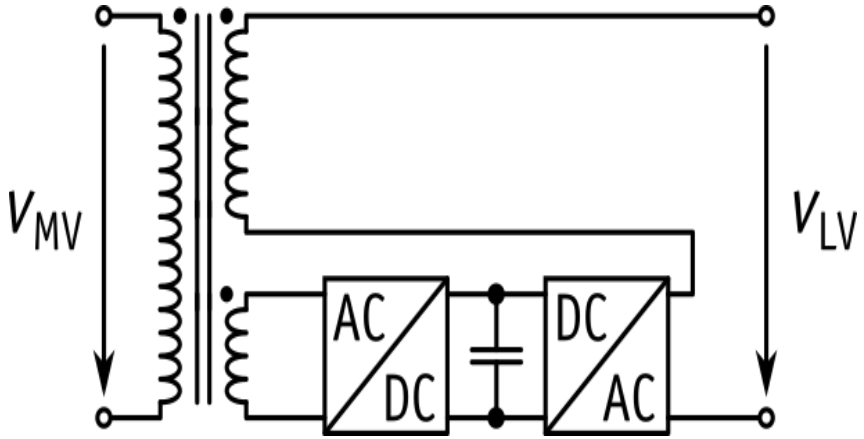
- **Key technologies**
  - ✓ **Power device:** 1200V/25mOhm SiC MOSFET, 4 cells in for 2.4kVrms; 650V/25mOhm GaN for LV
  - ✓ **Topology**: cascaded H-bridge boost +CLLC resonant converter with **500kHz** fixed frequency
- **Comparison between this SST solution and the conventional 50/60 Hz transformer + LV PFC converter**
  - ✓ Significant size reduction because the transformer operating at **500 kHz**
  - ✓ Peak efficiency: 98%
  - ✓ Suitable for reactive power control





Hybrid Transformers: Combinations of LFT and Low-Cost SST for Power Distribution

- **3X cost reduction**
  - ✓ SST mixing LFT solution : **MV partial power SST + high power LF transformer**
  - ✓ This SST do NOT process the full power flow, which results in significant cost saving vs. normal SST
- **Comparison between this SST solution and the conventional 50/60 Hz transformer**
  - ✓ Good candidate for future smart grid application
  - ✓ Combining controllability of SST and low cost of LF transformer
    - Voltage scaling & galvanic isolation
    - Correction of voltage sags, unbalances and phase angle errors
    - Reactive power compensation
    - Can be extended to bidirectional power flow control



Cooperation Opportunities

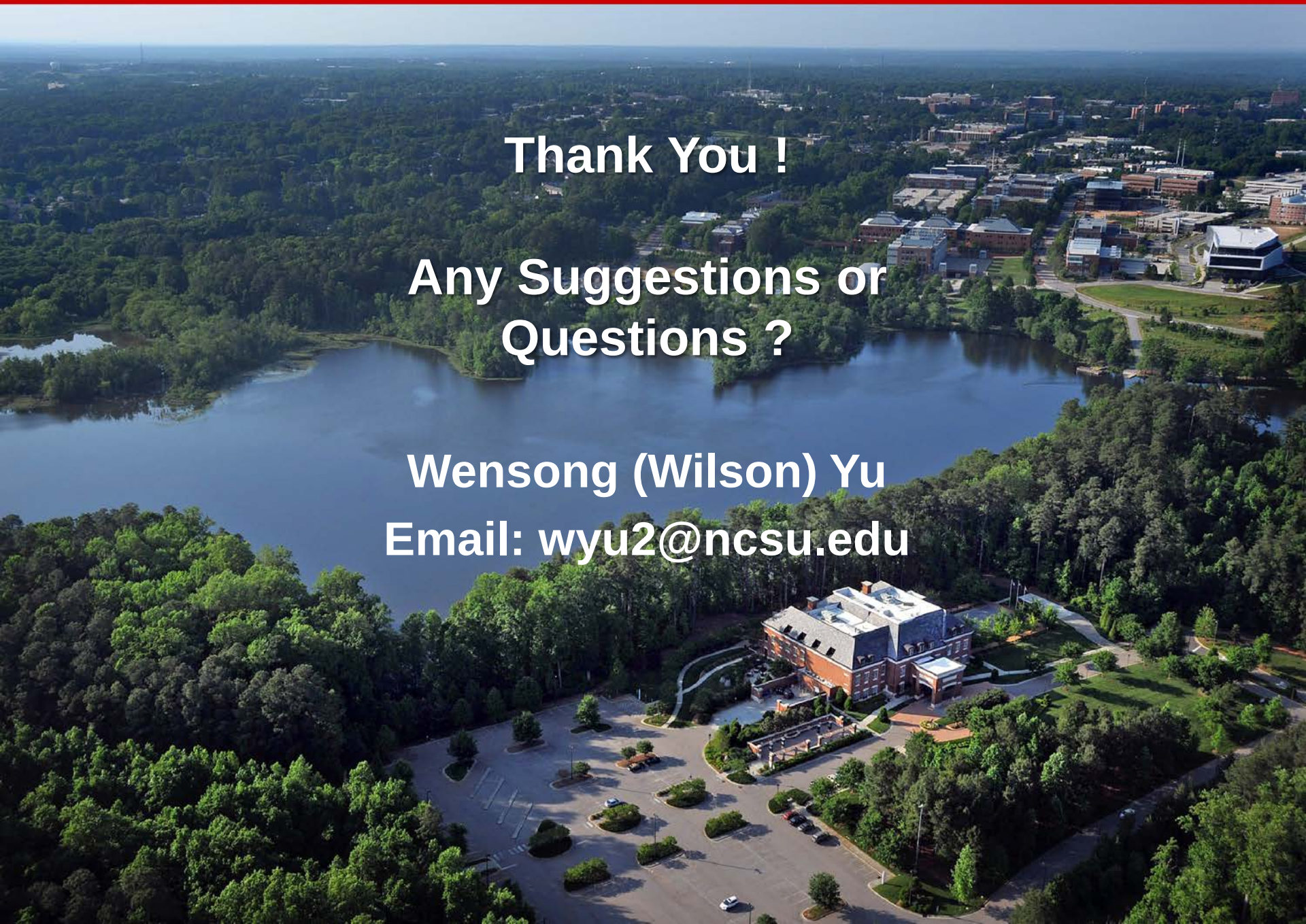
FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

ADVANCED RESEARCH PROJECTS AGENCY – ENERGY (ARPA-E)
U.S. DEPARTMENT OF ENERGY

CREATING INNOVATIVE AND RELIABLE CIRCUITS USING INVENTIVE TOPOLOGIES AND SEMICONDUCTORS (CIRCUITS)

Cooperation Opportunities

- ✓ **Topologies and control methods that combine multiple functions (e.g. rectification and step-down) into one single topology with reconfigurable power flow paths**
- ✓ **EMI free MV circuit topologies, zero-voltage and/or current switching with minimum magnetics**
- ✓ **Power-over-fiber based gate drive with comprehensive protection functions for >10kV SiC power devices**
- ✓ **HV and reliable solid-state transformers (SST), circuit topologies capable of >1000 kW of power conversion**
- ✓ **Combined bi-directional ac-dc charger and dc-dc converter**
- ✓ **480Vac 3 phase to ≥ 900Vdc converter, compact sub 2-minute EV charging stations with reduced installation cost**



Thank You !

Any Suggestions or Questions ?

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