Medium Voltage Solid State Transformer for Grid Applications; Opportunities and Challenges

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Overview

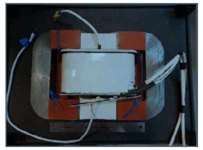
- SST Topology Selection
- MV SST Topology
- Design Challenges
- MV SST Applications
- Utility Requirements
- Outlook

Solid State Transformer Topology

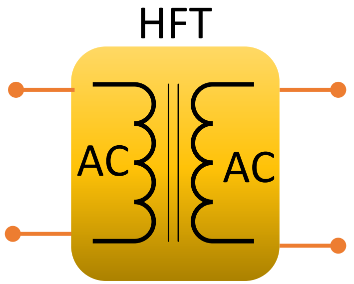
- Needs
  - High Power Applications
  - Distribution Voltage Level – MV (> 4.16 kV)
  - Bidirectional Power Flow
  - Enhanced controls (power, voltage, distribution)
  - Renewables adaptable
  - High Power Quality
  - Active Filtering
  - Agile and Stabilizing
  - Power Router

Freq.	50Hz	10kHz
Power	2MW/unit	56kW/unit
Quantity	1pcs	36pcs
Power density	0.77kW/L	14kW/L
2MW weight	6000kg	666kg

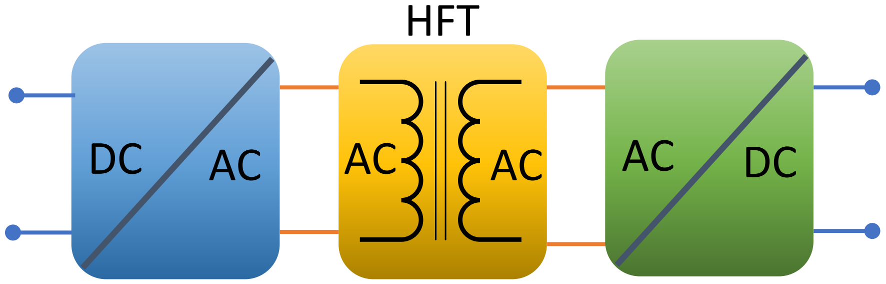
- Topologies - Derivation
  - Operating Voltage → Multilevel OR Multiple Devices in Series
  - High Control Bandwidth → High Switching Frequency
  - Flexible Power Router → DC Bus Distribution
  - Isolation (safety) → Transformer
  - Small Volume / Footprint / Weight → HF Magnetics



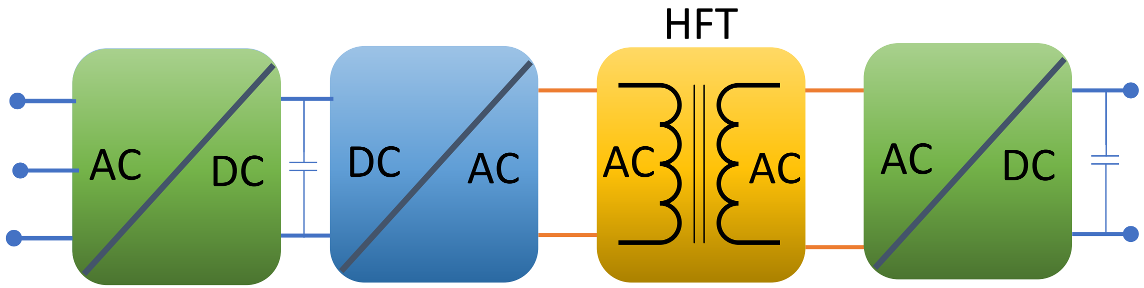
Solid State Transformer Topology Selection



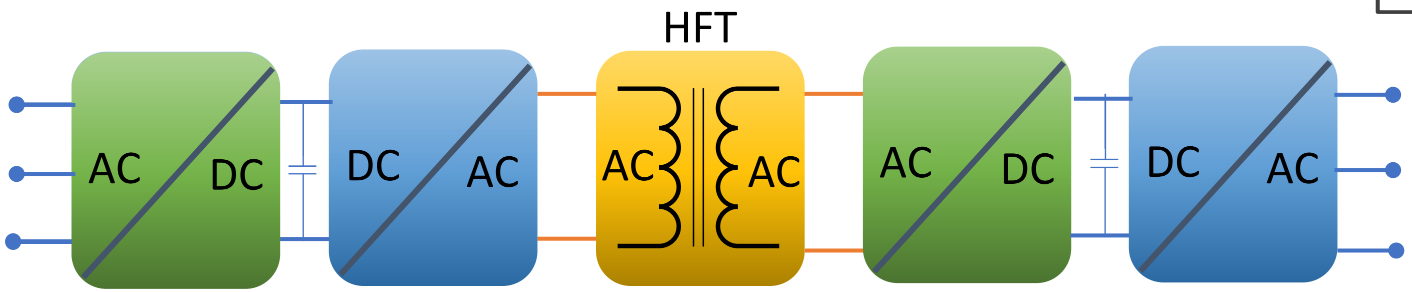
HF Transformer



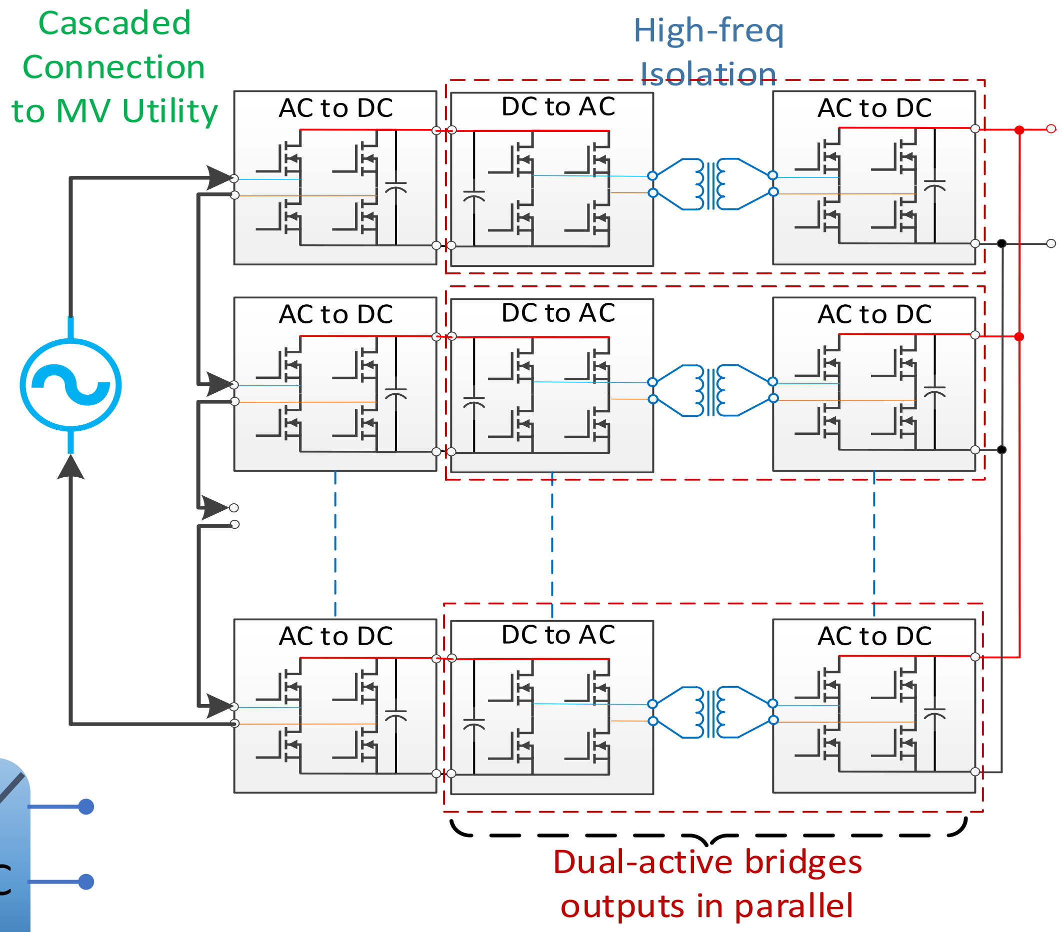
Two Stage DC ←→AC



Three Stage AC←→DC

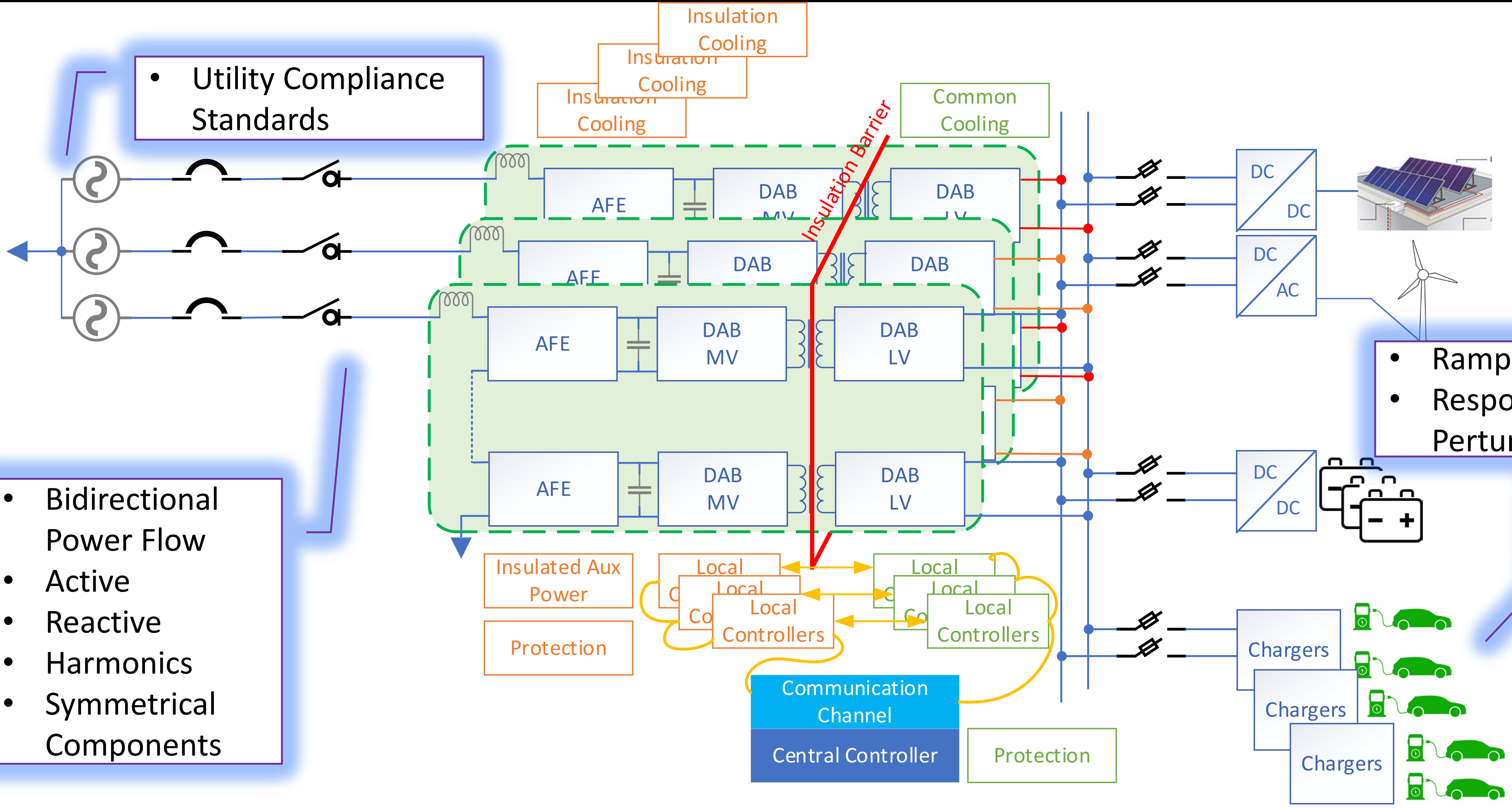


Four Stage AC←→AC



Topology Selected MV SST and Design Challenges

- Utility Compliance Standards



- Bidirectional Power Flow
- Active
- Reactive
- Harmonics
- Symmetrical Components

- Ramp Rates
- Response to Input Perturbances

MV SST Design Challenges

- Low Short Circuit Capability

- Isolation
  - 95 kV BIL for 15 kV Class
  - Transformer Fabrication
  - Isolation Power Supply for Hotel Power
  - Cooling Loop Conductivity

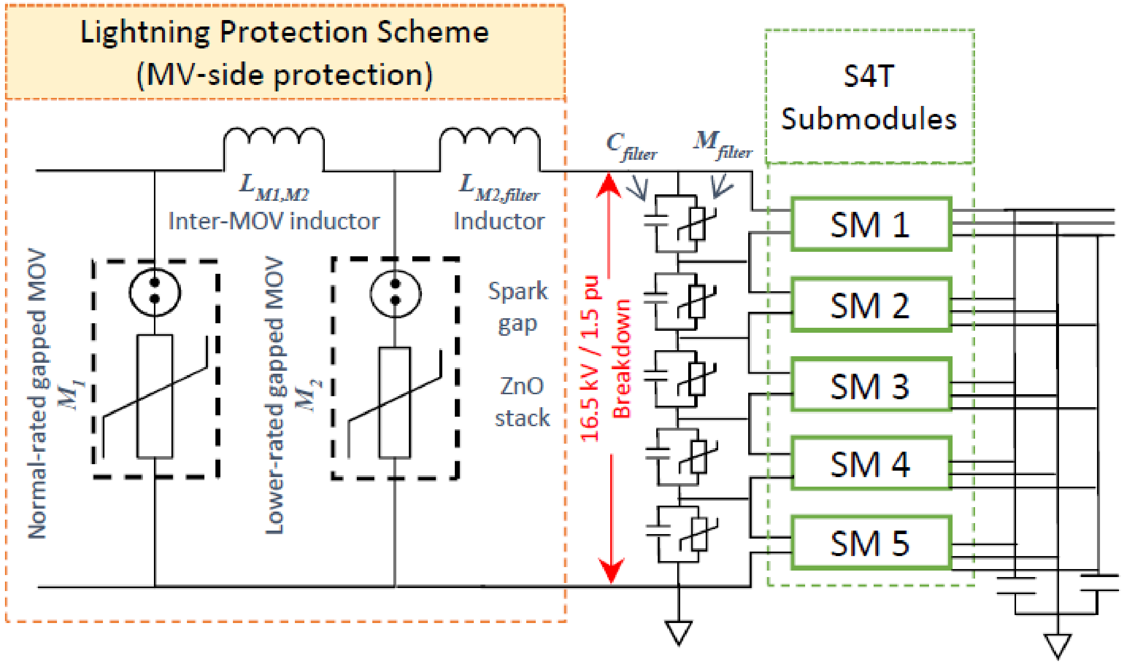
- EMI and Common Mode Voltages

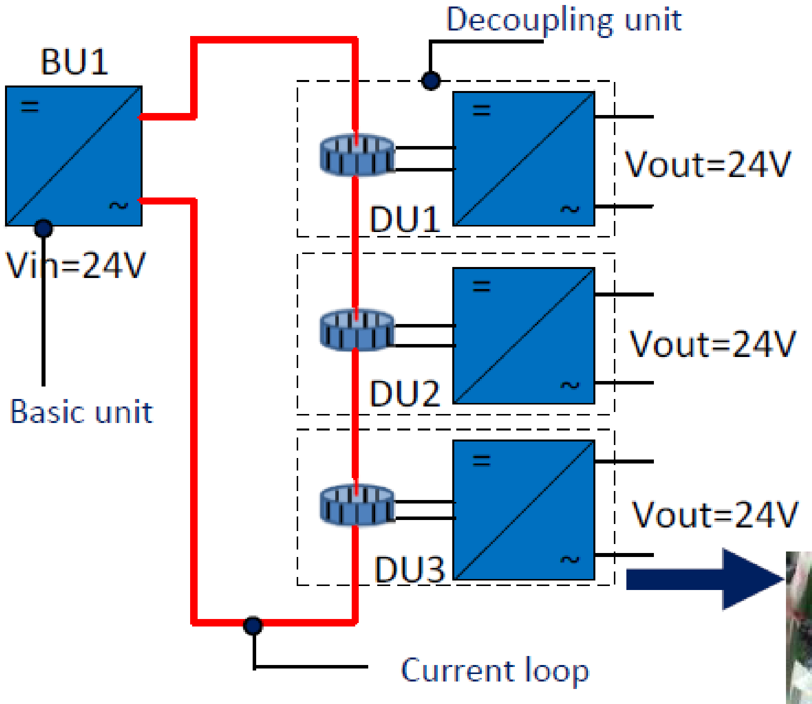
- Complex Controls & Communications
  - AFE: MV DC Bus Voltage Balancing
  - DAB: Power / Current Balancing
  - Central Controller serving all levels – communication protocol

- HF Transformer
  - HV Insulation
    - Partial Discharge
    - LV←→MV BIL of 95 kV required
  - Parasitic Capacitances → Stray Losses, EMI
  - Core and Windings Insulation
  - Core Cooling often required (HF ←→size)

- Thermal
  - Individual Cooling Loops for each level
  - Advanced Materials Use
    - Phase-change
    - Immersive Cooling
- Switching Devices
  - Soft-Switching at all power levels
- MV DC Bus Capacitance optimization

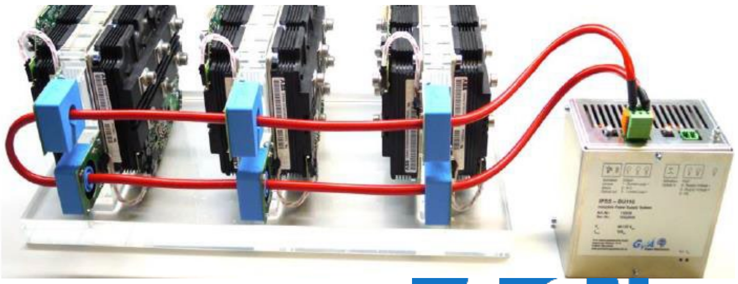
Selected MV SST Design Challenge Mitigations





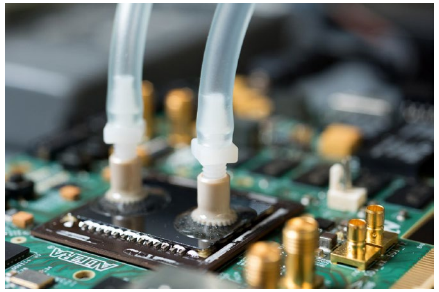
- Front End (MV) Protection
- 15 kV Class → BIL 95 kV

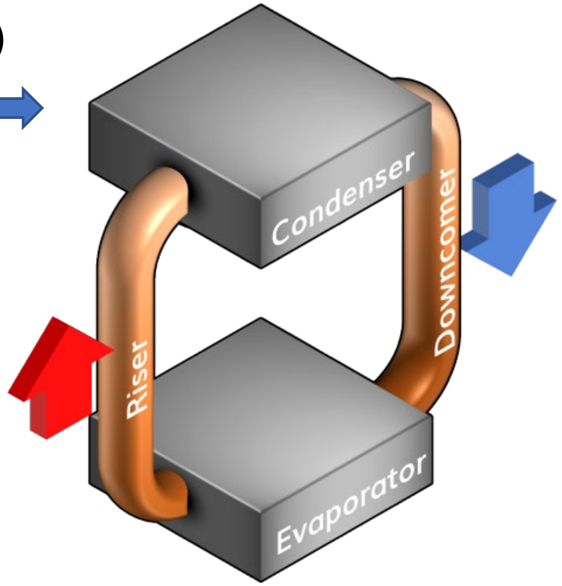
- Isolated Power Supplies
  - Gate Drivers
  - Local Controllers Supply

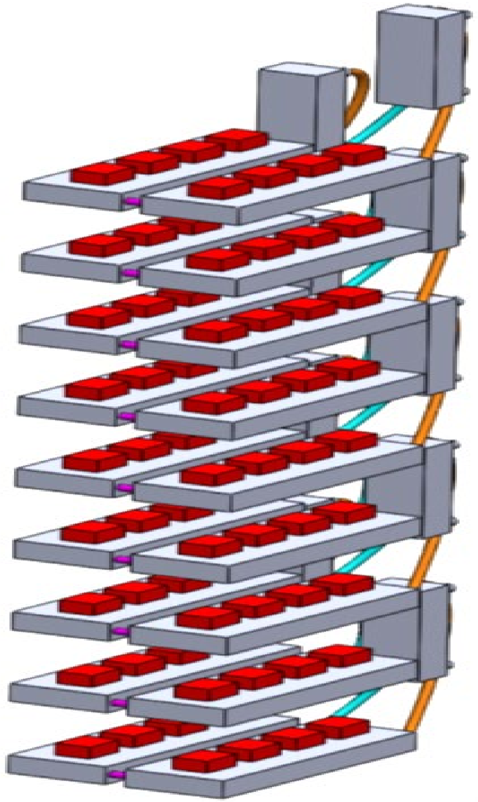


Selected MV SST Design Challenges Mitigations (cont.)

- Cooling
  - MV Conversion Stage Electrically "Floating"
    - Cold-plates in series/parallel: De-Ionized Water (reliability and maintenance concerns)
    - Individual Cold-plate Loops (modular, integrated with Level converters, require secondary loop)
    - Advanced Cooling (materials, coolant types, pumpless)
      - Thermosyphon
      - Immersive Cooling

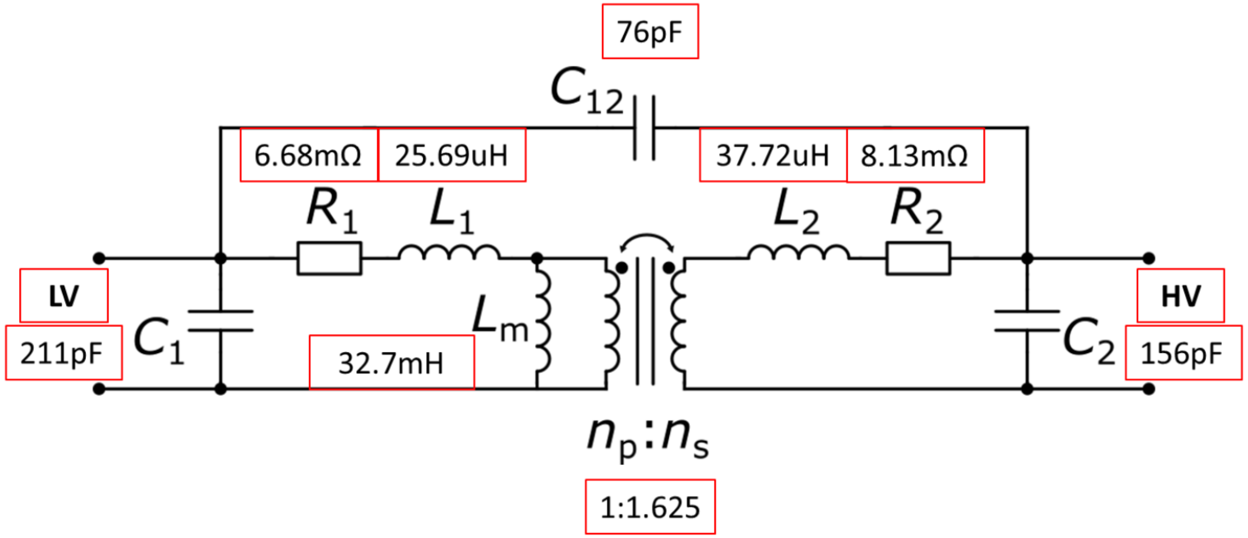






- HF Transformer
  - Shielding

HF Transformer Characterization: MV SST Parasitics



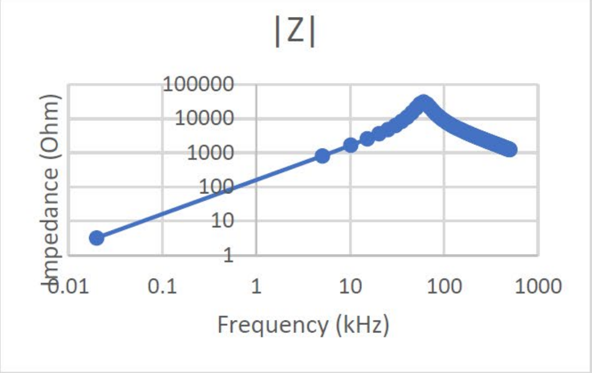


Fig. 2 HV OC Impedance

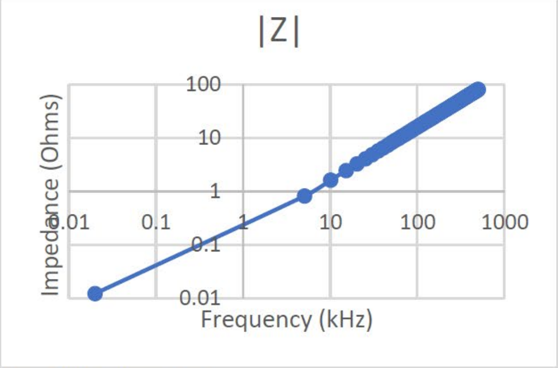
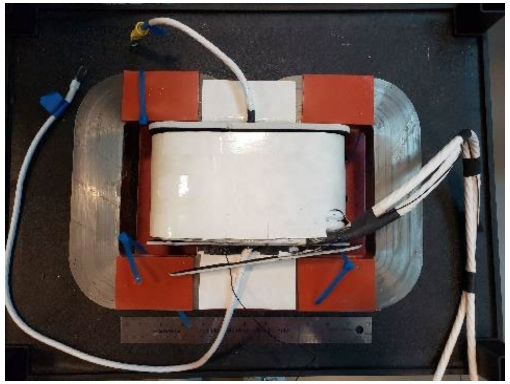


Fig. 3 HV SC Impedance



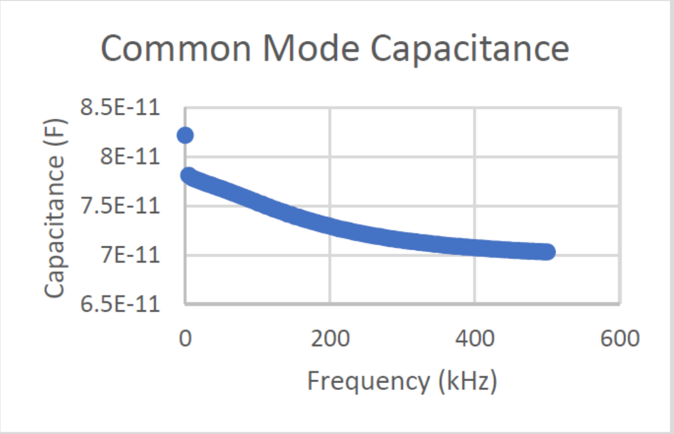


Fig. 6 Common Mode Capacitance

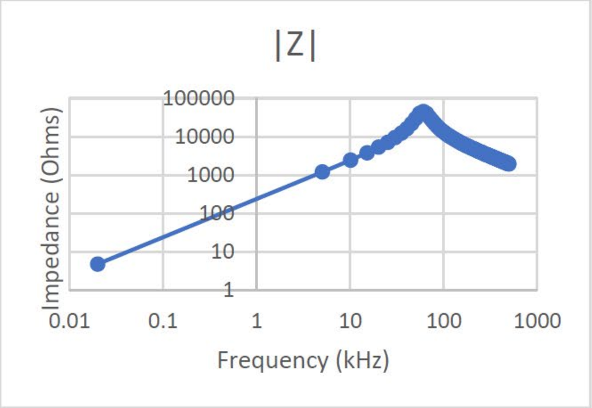


Fig. 4 LV OC Impedance

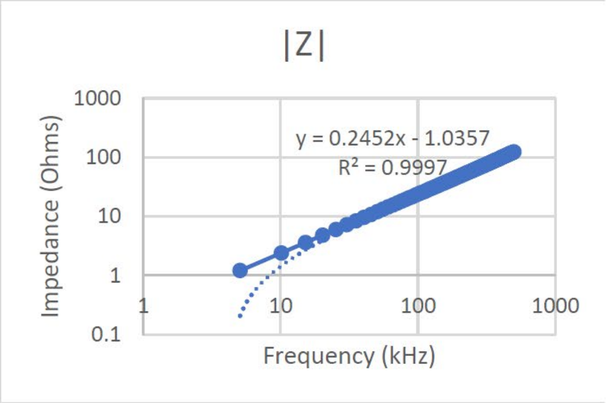
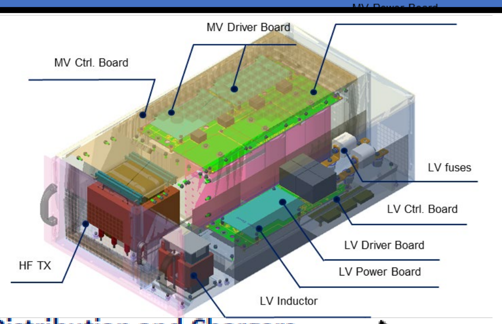
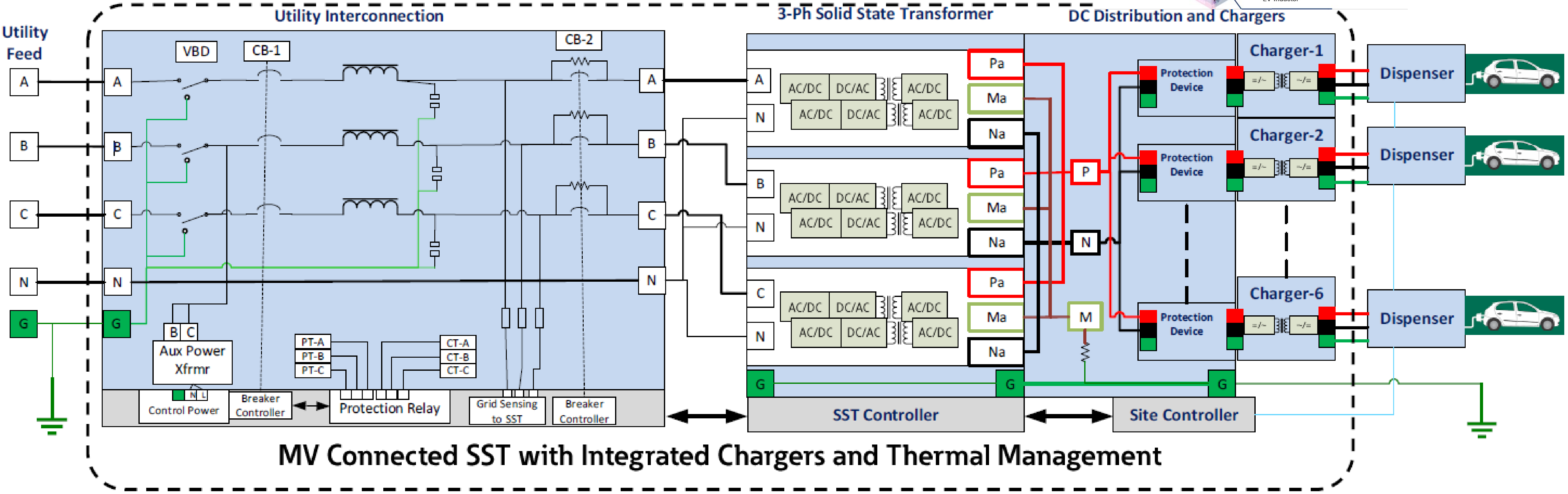


Fig. 5 LV SC Impedance

MVSST Application: Fast EV Charging (Development)

- Vgrid = 13.2 kV
- P = 2.5 MW
- PF = 0.95 Lead/Lag
- DC Distribution: 800 VDC





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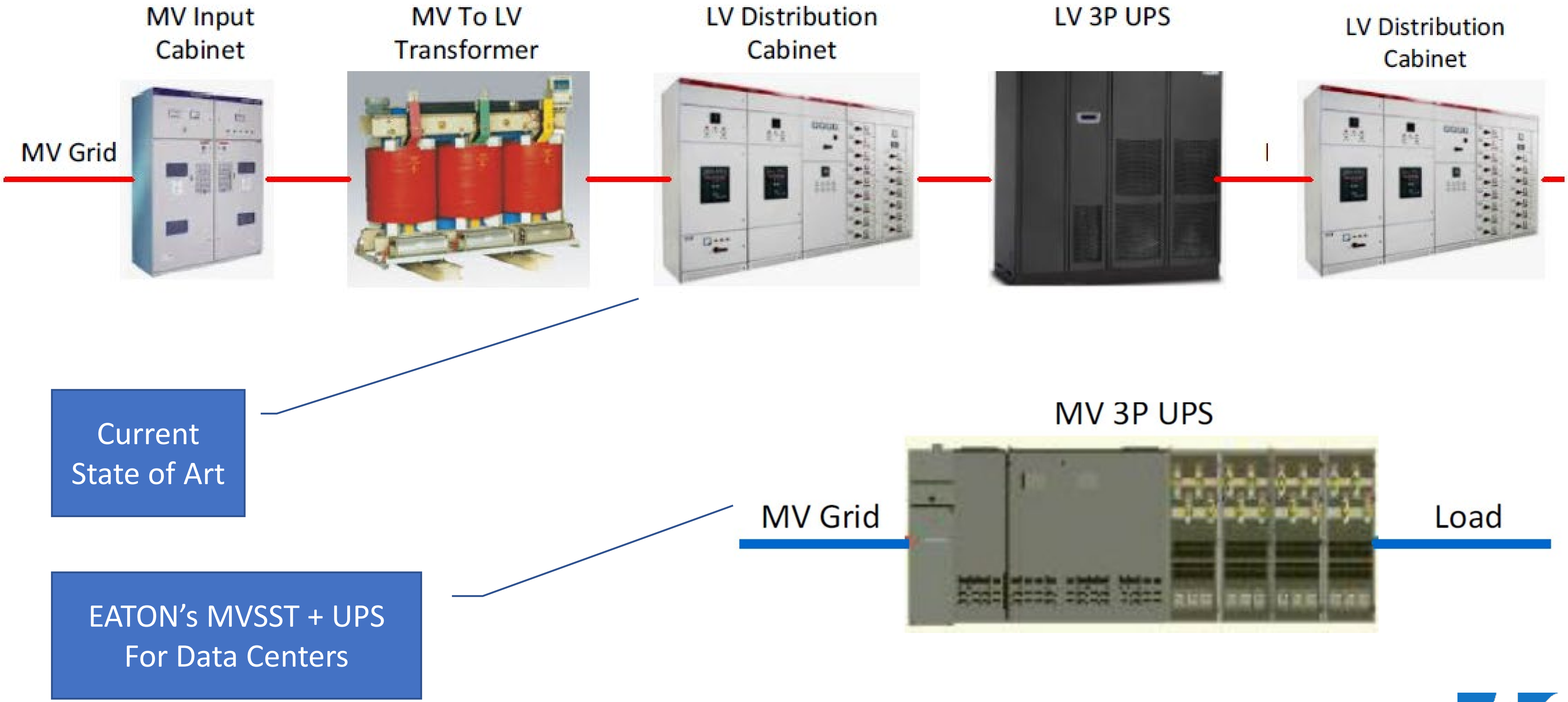
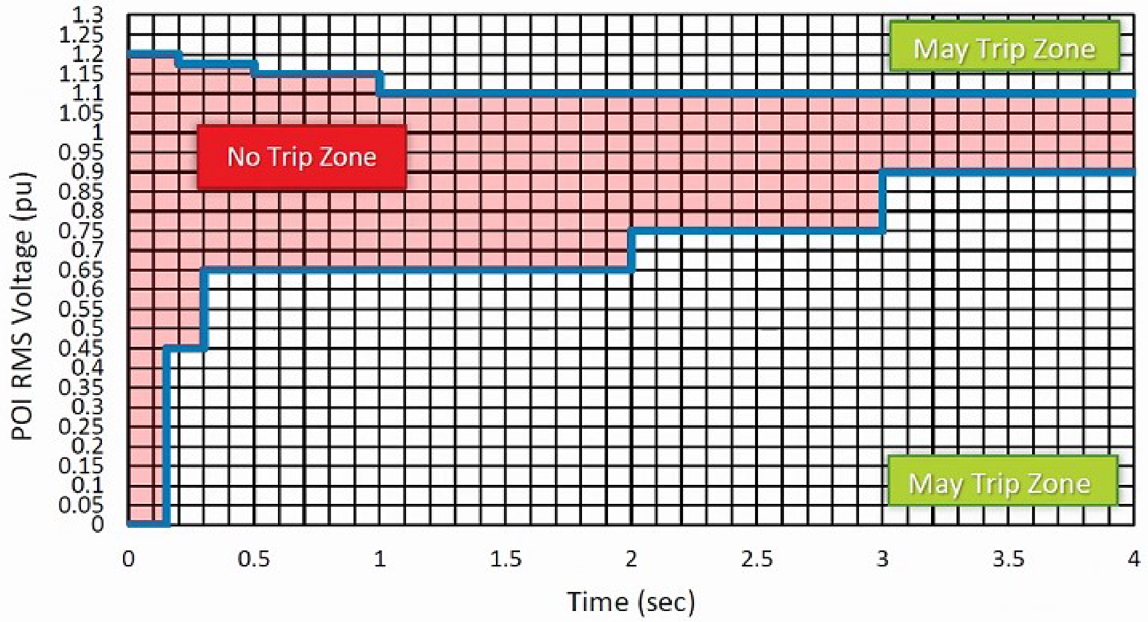
Data Center Power Distribution with MV SST



Utility Connection Standards

High Voltage Ride-Through		Low Voltage Ride-Through	
Voltage (p.u.)	Time (sec)	Voltage (p.u.)	Time (sec)
≥ 1.2	Instantaneous Trip Allowed	< 0.45	0.15
≥ 1.175	0.20	< 0.65	0.30
≥ 1.15	0.50	< 0.75	2.00
≥ 1.1	1.00	< 0.90	3.00



Voltage Ride-Through Envelope

- IEEE 1547-2018 if exporting power
- CA Rule 21
- IEEE P2030.13
- SAE 1372
- IEEE 519-2022
- IEEE Std 1668™-2017
- ANSI C84.1-2020

Critical Areas For SST Development

- Modular / Expandable Single Grid-Connecting Topology
  - “Stackable” in Voltage
  - Ease of paralleling
  - Multi-functional (High Bandwidth)
    - Grid-side control (power flow, voltage regulation, active filtering, supporting symmetry, active damping of transients)
    - DC bus connected energy resources management
      - Grid stability support
      - Real-time energy dispatching
- Central Controller as dispatching and monitoring
  - Smart Local Controllers handle modules operation and protection
  - Use of Internal PLL for HF signal synchronization
- Self powering of individual levels (power Bootstrapping),
- Development of new core materials for high efficiency, high flux density HF Transformers
  - XFR Flux “Centering” active controls → further reduction of core volume

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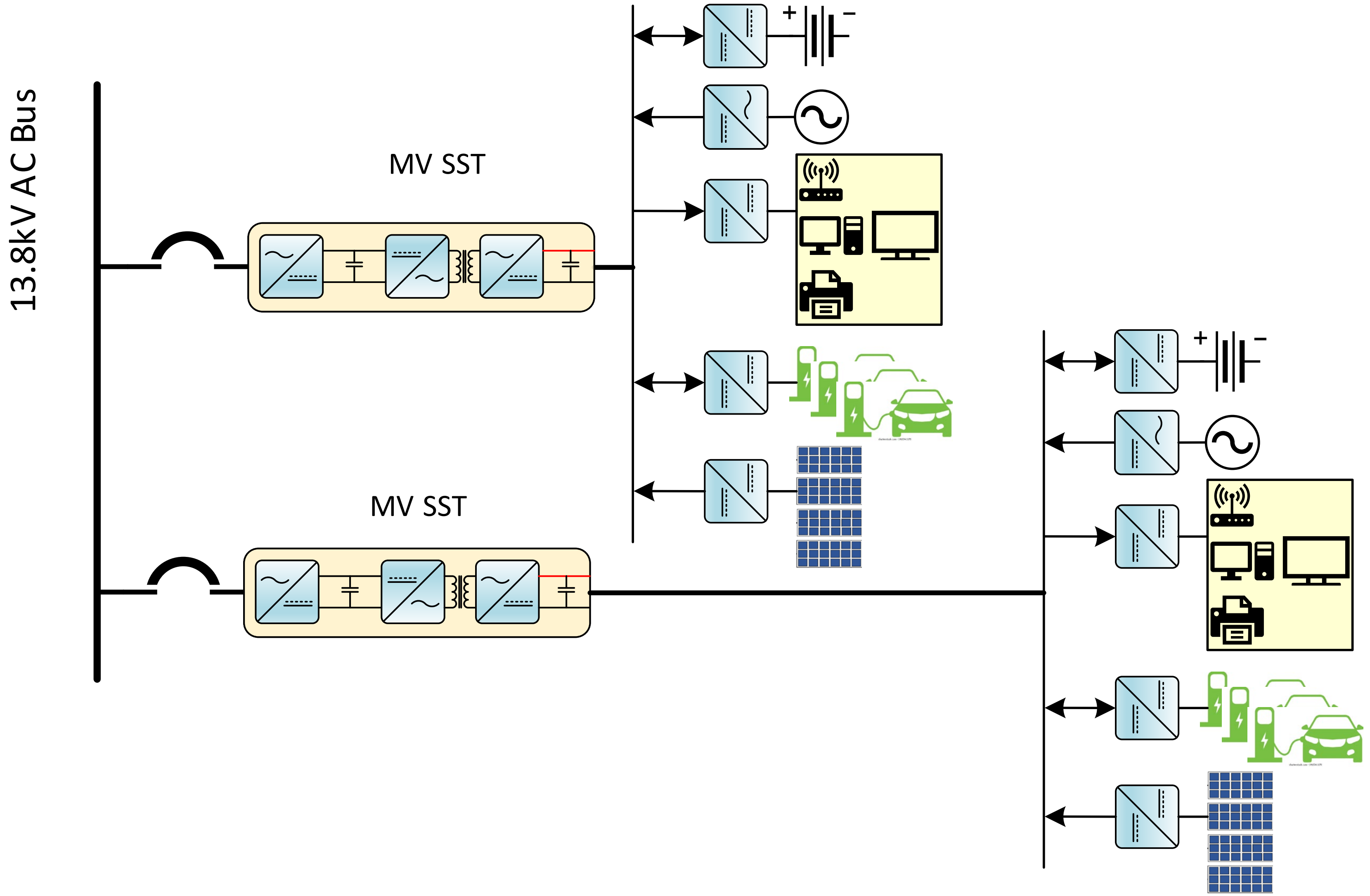
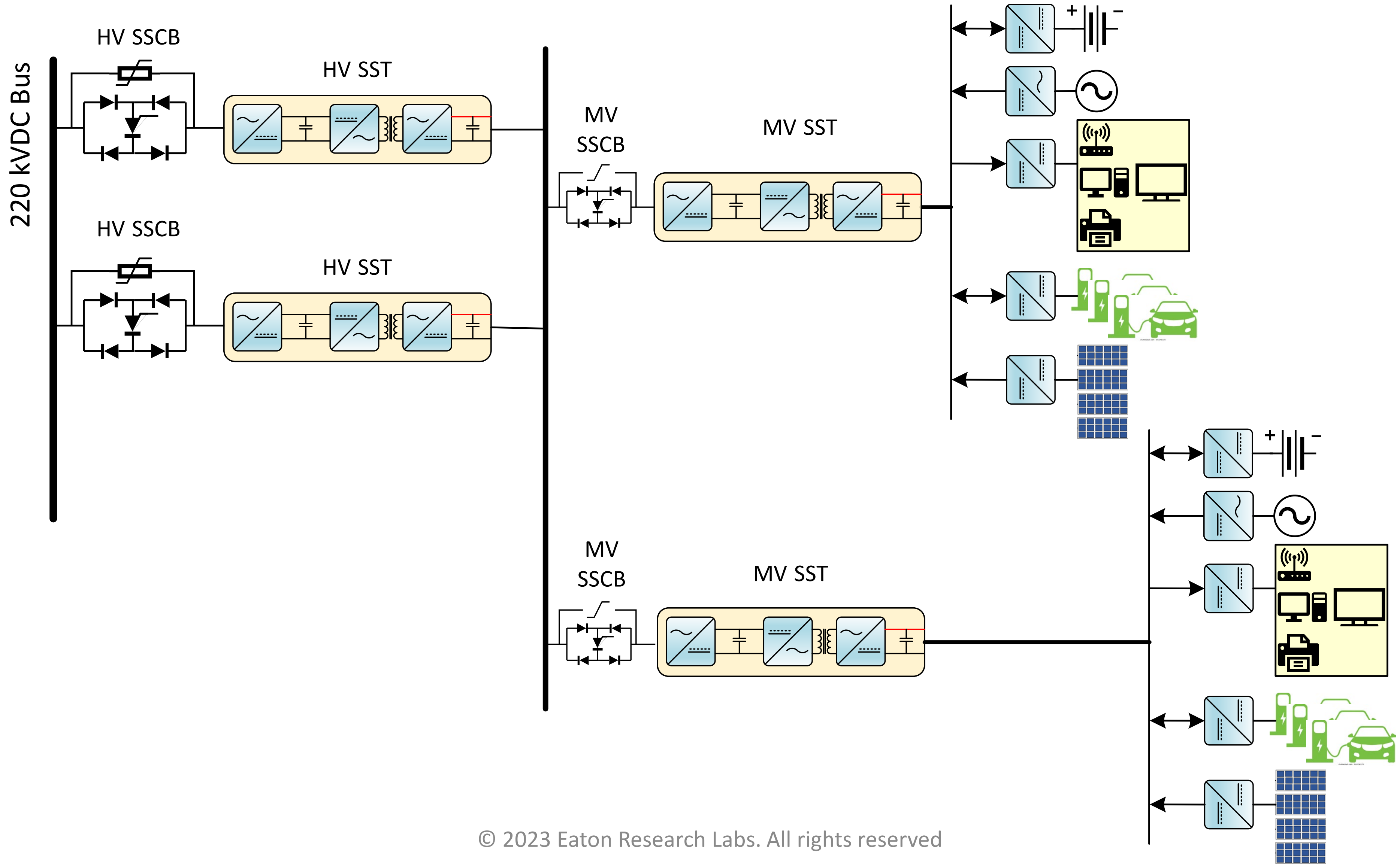
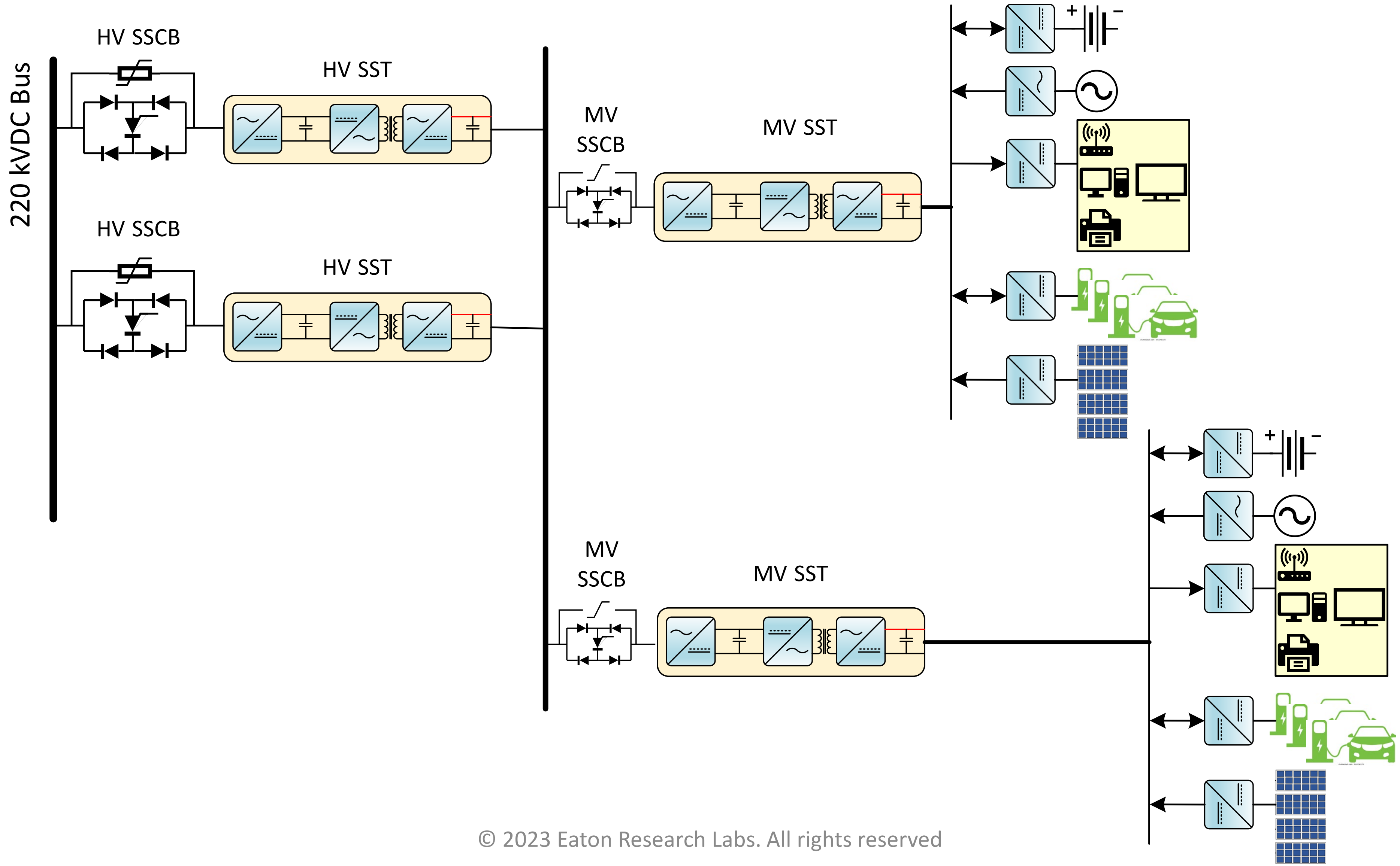
Transition to DC Transmission with MV SST



Transition to DC Transmission with HV SST



Transition to DC Transmission with HV SST



Thank You !

Questions?

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