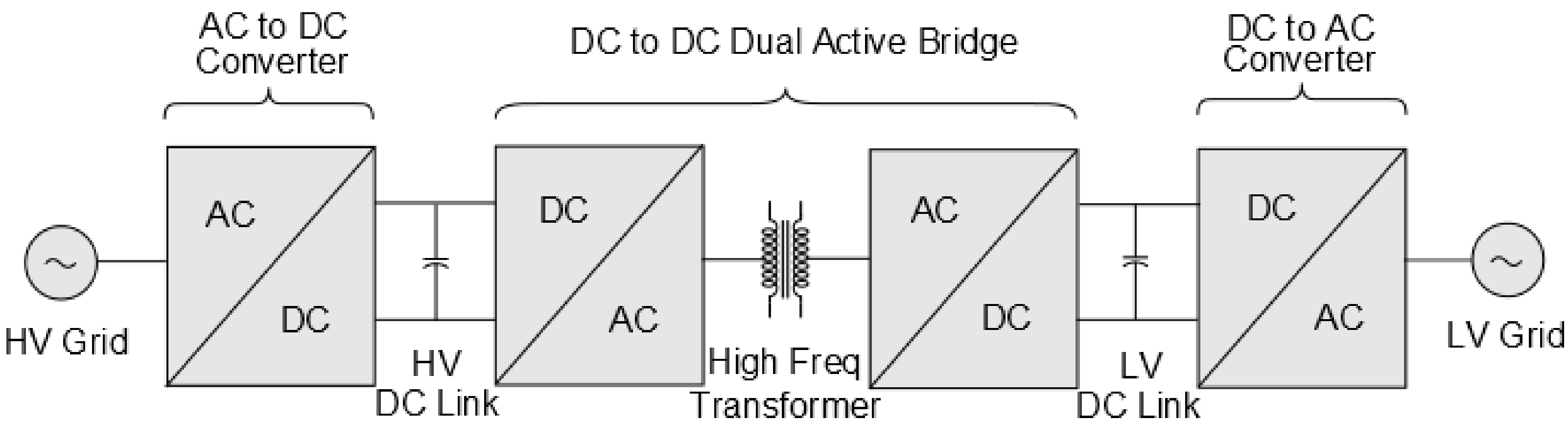
Magnetics for Solid State Transformer

Solid State Transformer (SST)

Motivation:

- Classical 60/50Hz transformers are bulky
- Minimal features : voltage stepping and galvanic isolation
- Additional features and size reduction with high frequency switching transformer

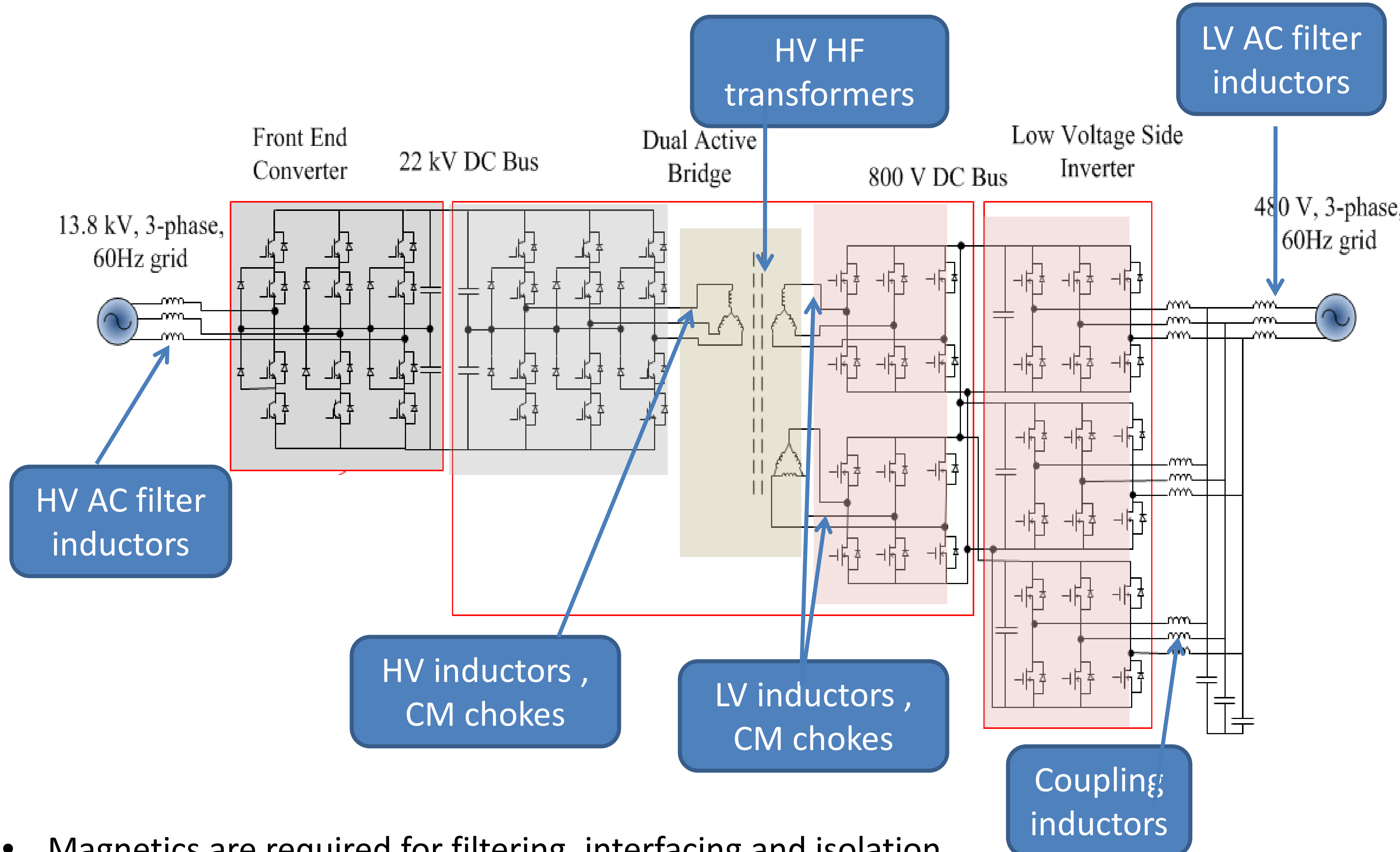
Three stage SST



Features:

- Active/Reactive power control at HV and LV both grids
- Integration of both AC and DC renewable energy sources
- High frequency isolation
- Intelligent fault management

Magnetics for SST



- Magnetics are required for filtering, interfacing and isolation
- HF switching transformer is the one of the key elements enabling SST

Magnetics for SST

Magnetic materials

Material	Composition	Loss(w/kg) (0kHz,0.2T)	Saturation B_{max}[mT]	Permeability (50Hz)	Max working Tem[°C]
Grain oriented silicon steel	$Fe_{97}Si_3$	>1000	2000	2k-35k	120
Fe-amorphous alloy	$Fe_{76}(Si.B)_{24}$	18	1560	6.5K-8K	150
High performance ferrite	MnZn	17	500	1.5K-15K	100/120
Nanocrystalline alloys	FeCuNbSiB	4.0	1230	20K-200K	120/180

- Critical parameters are high saturation flux density and low losses

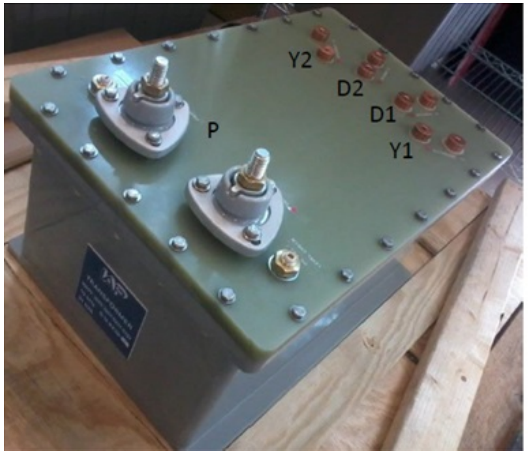
High Voltage Switching Transformer

- **Specifications**

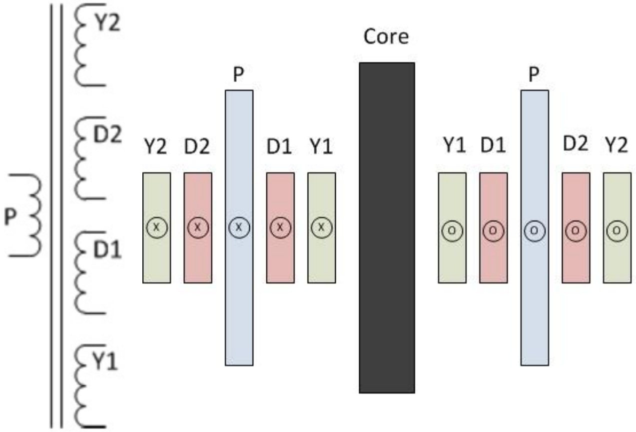
Parameter	**Values**
Power	35 kVA,11 kV/22 kV dual mode
Primary	9.6 kV RMS, 16.6 kV peak,8 A RMS, 12A peak
Secondary – Y winding 1 ,2	360 V RMS , 605 V peak,52 A RMS, 83 A peak
Secondary – Delta winding 1 ,2	625 V RMS , 1050 V peak,31 A RMS, 46 A peak
Frequency	10 kHz
Leakage inductance	80 µH (from secondary side)
Magnetization inductance	280 mH (from primary side), Max. magnetizing current 15% of full load current
Parasitic capacitance (inter turn from primary)	<500 pF
Isolation primary to secondary	100 kV RMS
Cooling	Oil cooling
Efficiency	>99%

- Turns ratio, switching frequency ,leakage inductance are selected for optimum operation of DAB

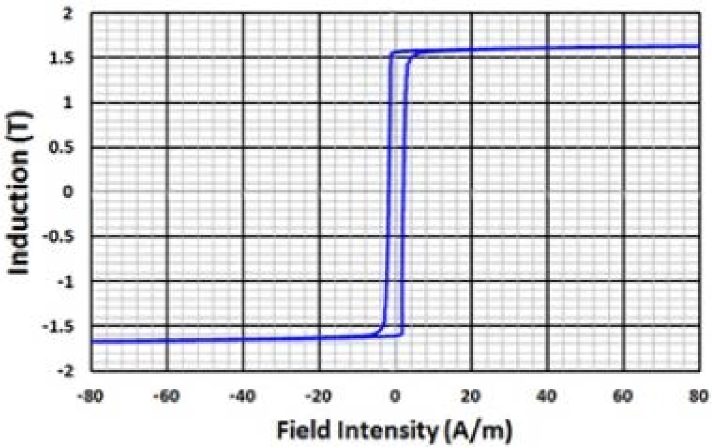
DAB High Voltage Transformer



Transformer



Windings arrangement

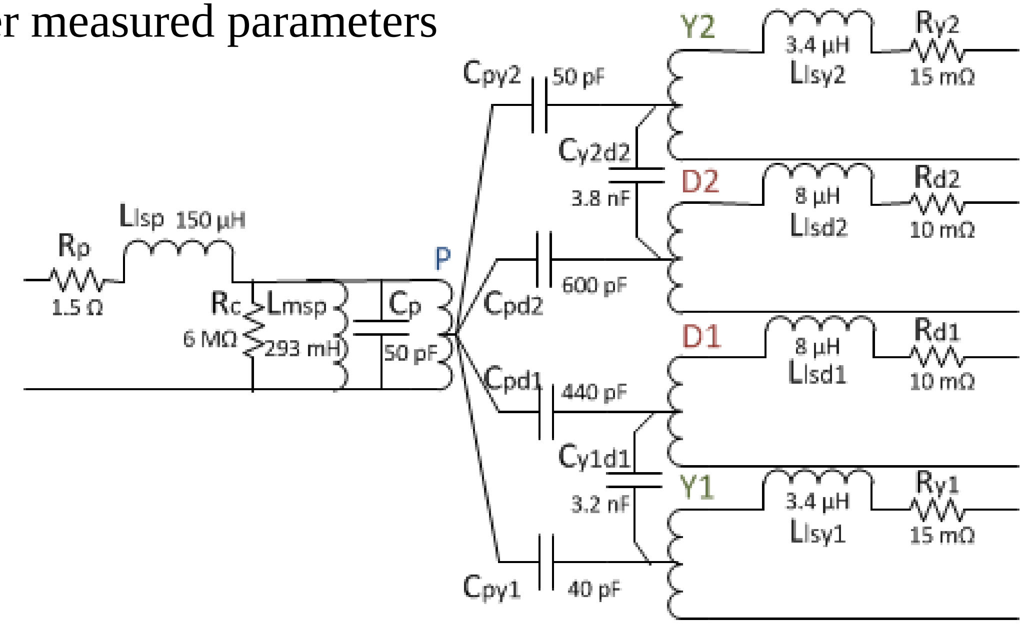


Magnetic core characteristics

- High frequency switching transformer is one of the key elements in SST
- Core material : nanocrystalline
- Filled with oil to achieve the required insulation level and thermal cooling
- Transformer design is very challenging to meet size, minimal parasitics and high leakage and magnetizing inductances

DAB HV Transformer Measured Parameters

Transformer measured parameters

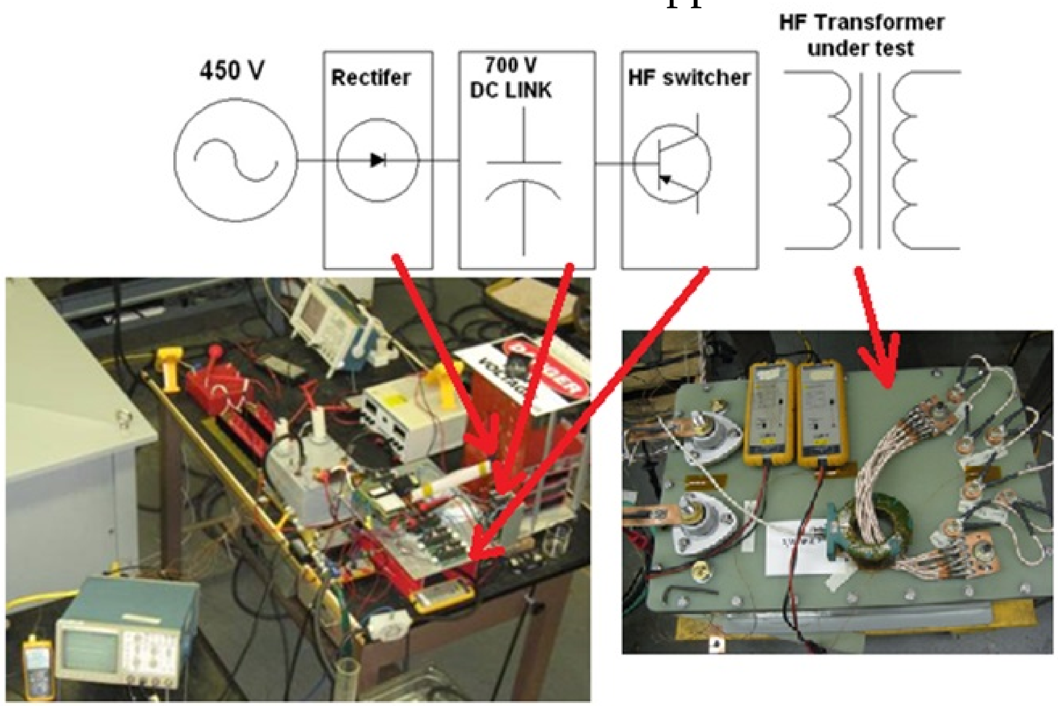


- Model parameters identified through impedance measurements
- The primary to secondary coupling capacitances (net 1.2 nF) are critical
- The transformer parasitics affect the system performance: poses control challenges

DAB HV Transformer Tests

Transformer tests

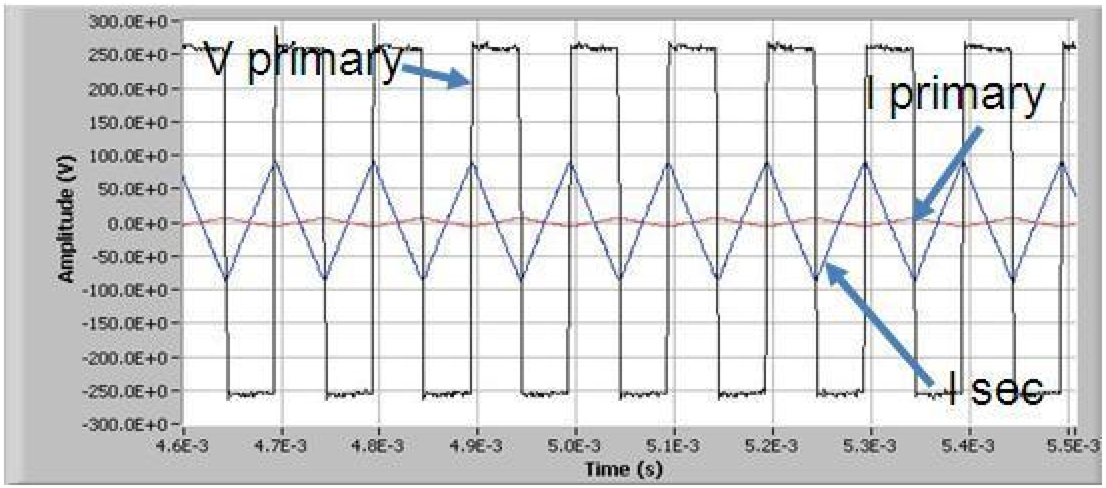
- Hipot test: insulation test
- Voltage transformation test
- Heat run test with secondaries open: core loss
- Heat run test with secondaries shorted: copper loss

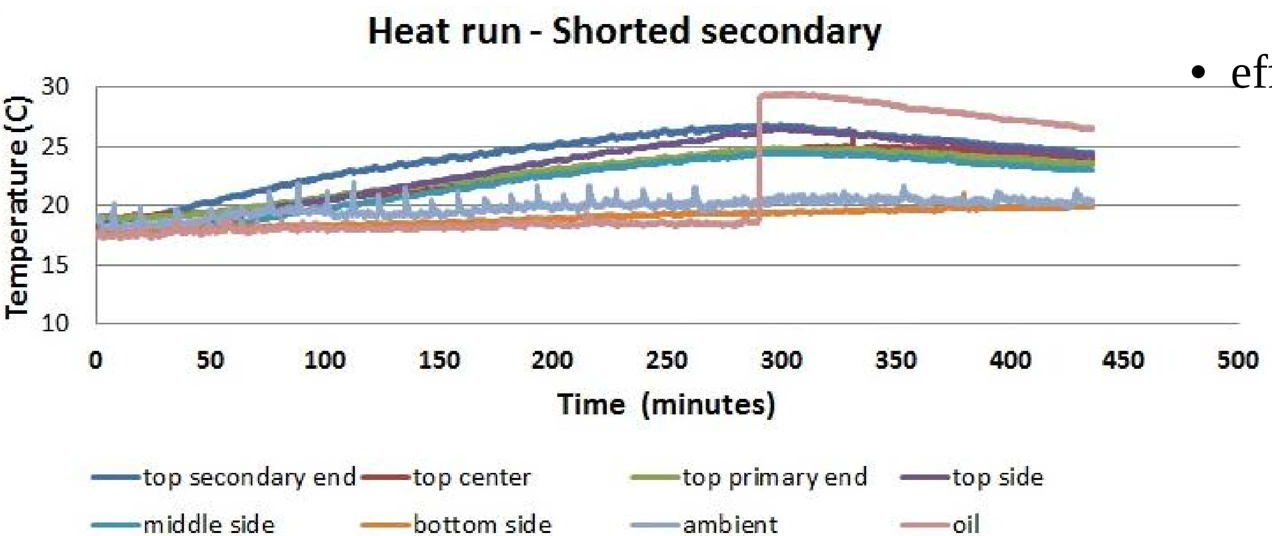


Transformer
test setup

DAB HV Transformer Tests

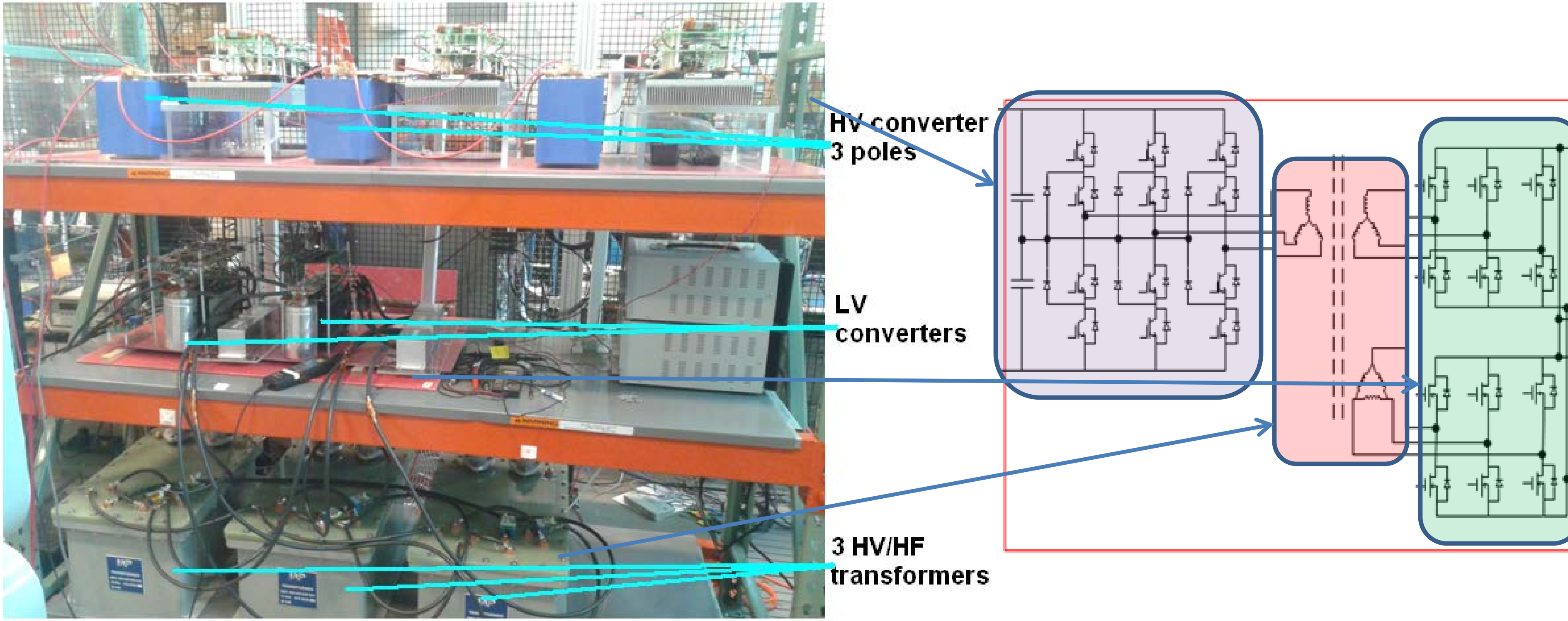
Transformer heat run test





- 25kVrms 1min across primary and secondary
- turns ratio: primary to Y is 26.7 and primary to delta is 15
- core loss 50W and copper loss 80W
- efficiency 99.6%

DAB Converter Setup

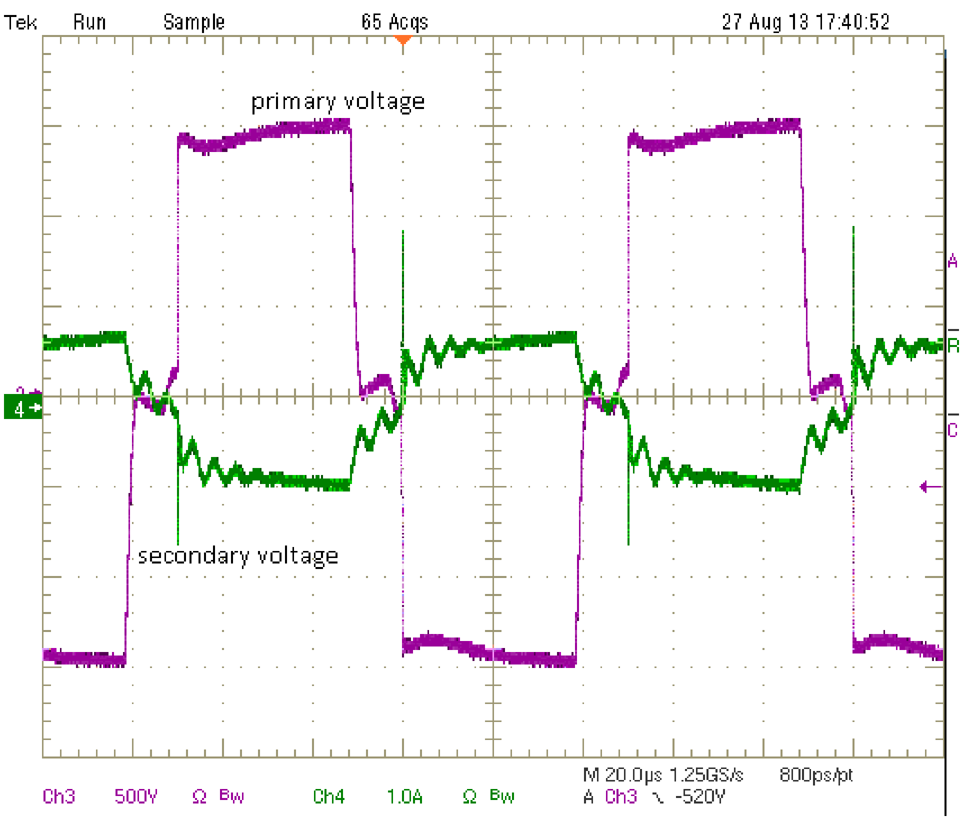


- Modular structure
- HV converter with IGBT Vcesat protection
- Digital controlled ,interfaced through central protection and conditioning card

High Voltage Transformer Switching Test

Resistive load switching

Switching test at 3kV,10kHz



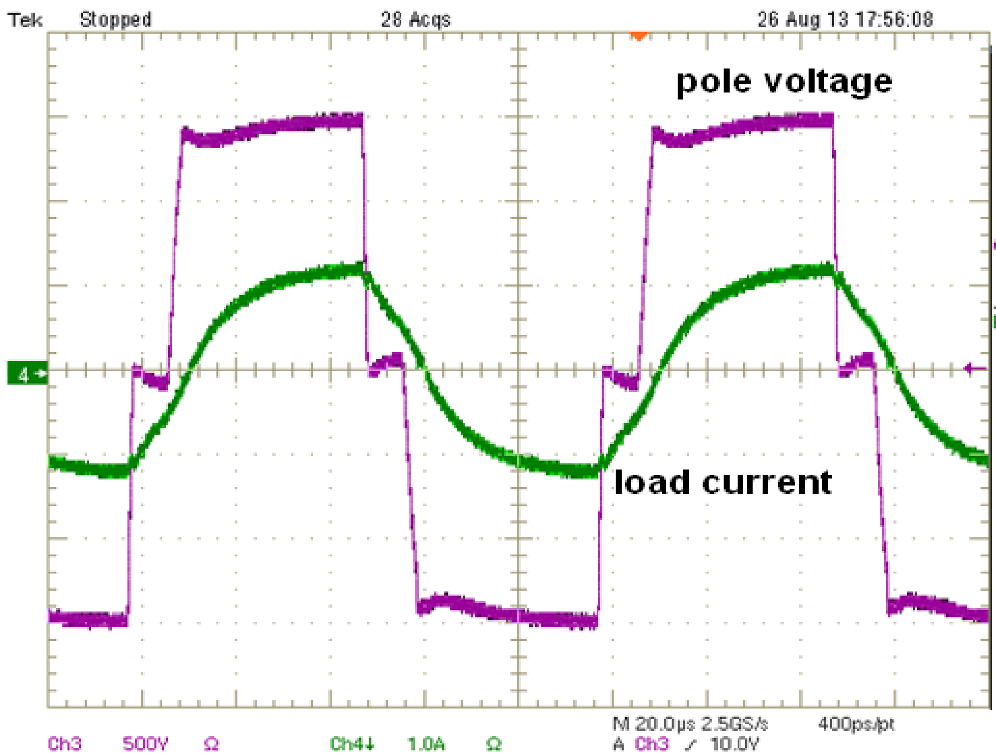
Transformer with secondary load of 800ohm and high voltage filter inductance of 400uH.

- To verify the switching characteristics of the transformers
- Only HV converter of the DAB used for switching tests
- All three DAB transformers had similar switching performance
- Hard switched, high di/dt at the switching instants

High Voltage Transformer Switching Test

Lagging load switching

Switching test at 3kV,10kHz

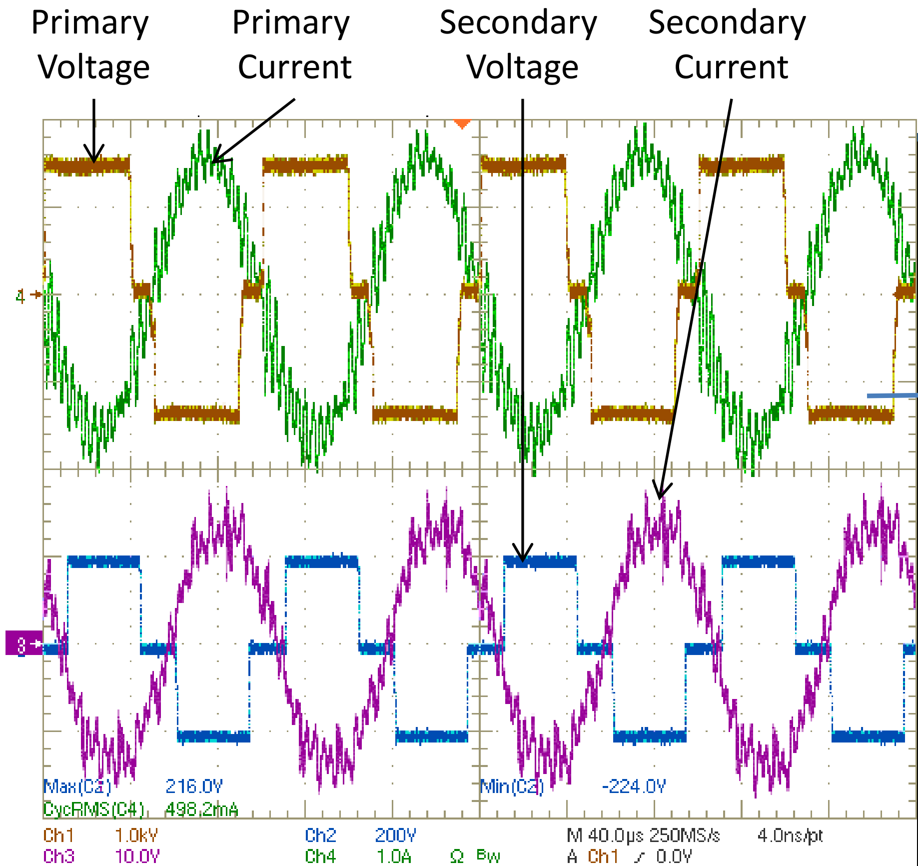


Voltage and current of a 3-level pole with lagging load (R=6Ω and L= 74 µH)

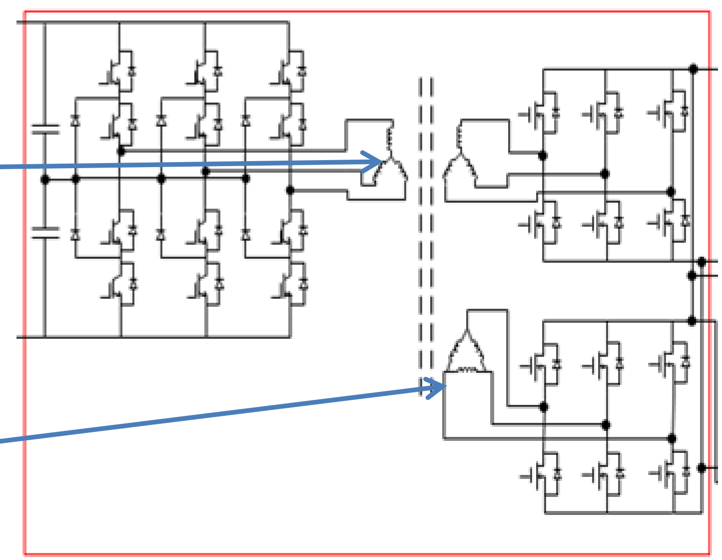
- The lagging load results in ZVS switching of the HV 3level converters
- Reduced di/dt

DAB Measurement Results

DAB operation at 3 kV primary side DC link with 5 kW load

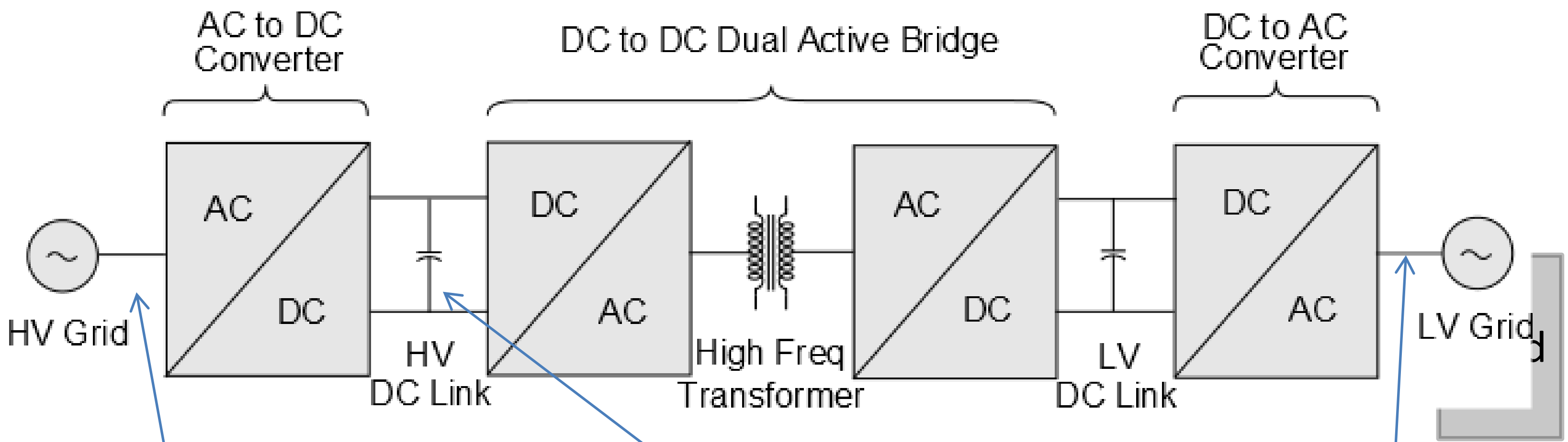


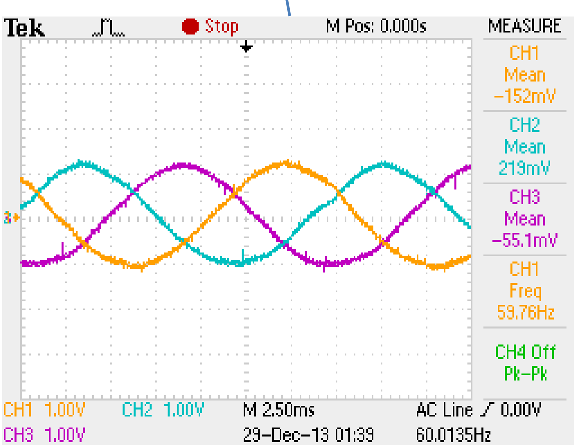
HVDC: 3kV
LVDC : 210V



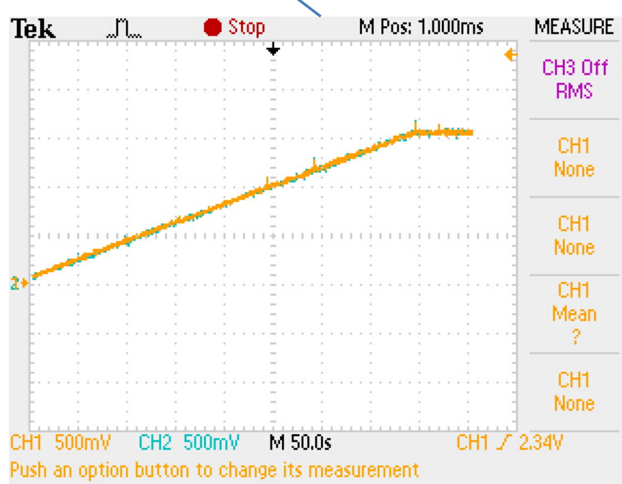
- Near sinusoidal current in DAB due to 3-level 3-phase topology and control advantages
- LC ringing in both primary and secondary currents due to transformer parasitic capacitors

SST Integrated Test

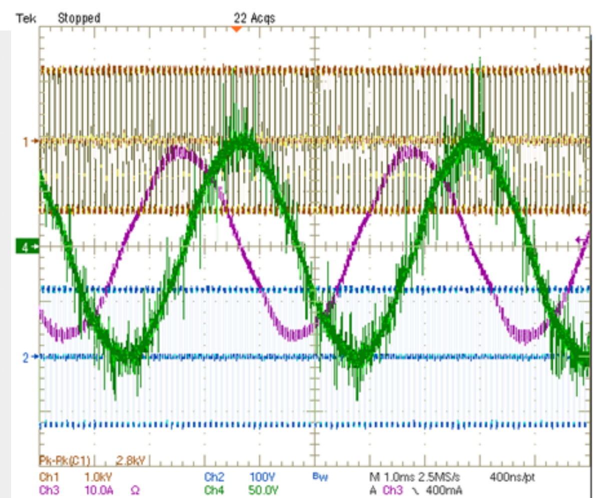




Line currents



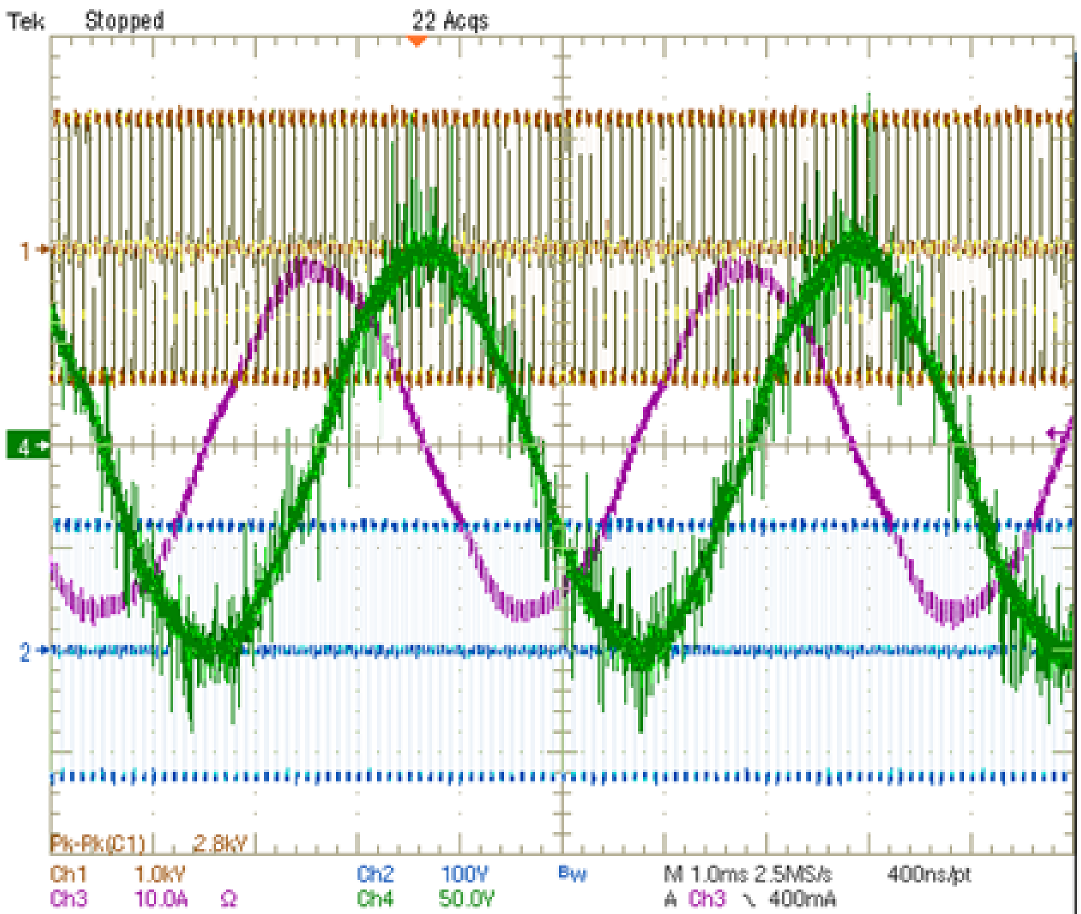
DC Link Charging



Output inverter line voltage and current

SST Integrated test

DAB waveforms of integrated SST



- Test at HVDC of 2.8kV
- LVDC of 210V
- Load of 2.3kW

DAB primary voltage: Ch1- 1 kV/div, DAB secondary voltage: Ch2- 100 V/div Inverter current: Ch3- 10 A/div, Inverter voltage: Ch4- 50 V/div)