What is the state of the art of Power Electronics Today?

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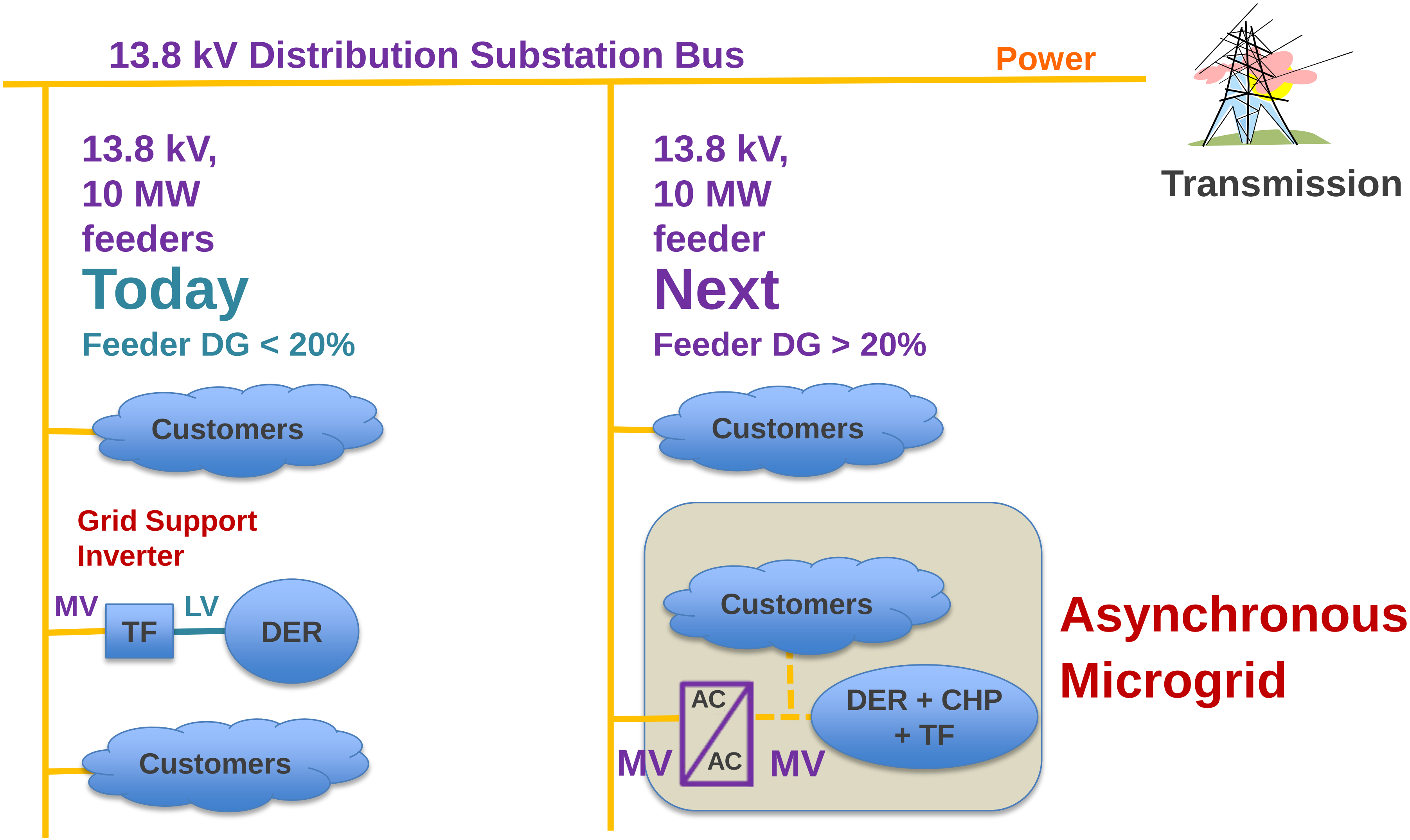
Outline

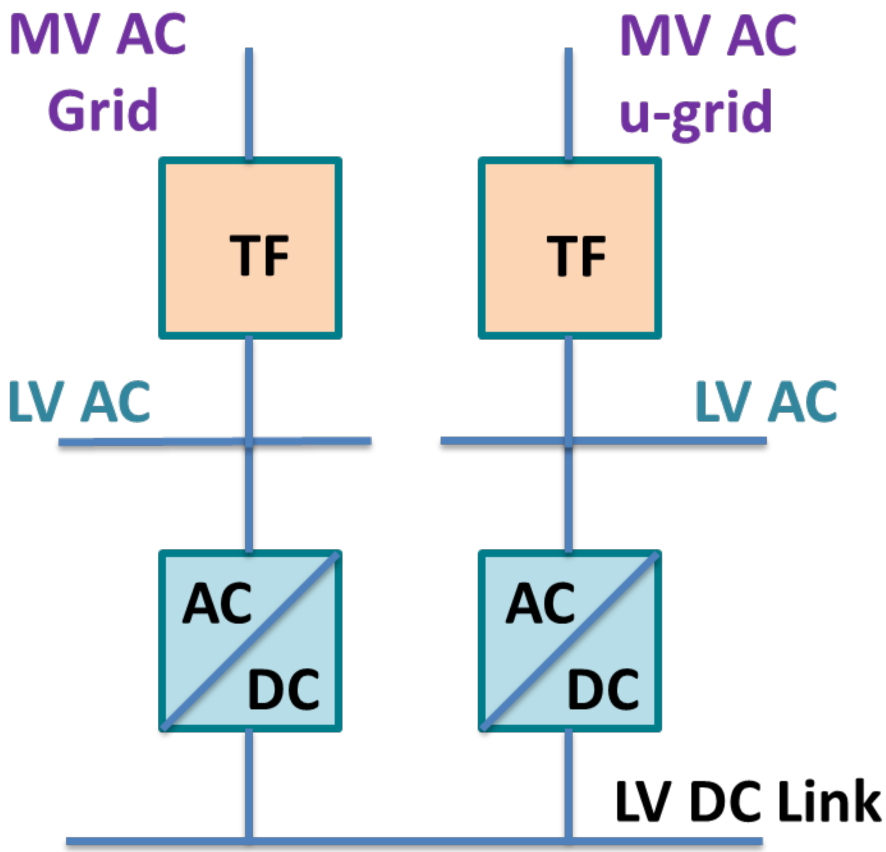
1. Microgrid to Macrogrid MV Asynchronous connections
2. Commercial HV SiC devices
3. Device level issues: Si IGBTs, Si Thyristors, Cosmic Rays
4. Cost model and manufacturing models
5. Gate Drives (OSU work)
6. Variable Speed Drive (OSU work)

1. Microgrid to Macrogrid MV Asynchronous connections



Courtesy of Dr. Allen Heffner, NIST

Si Solution is very expensive



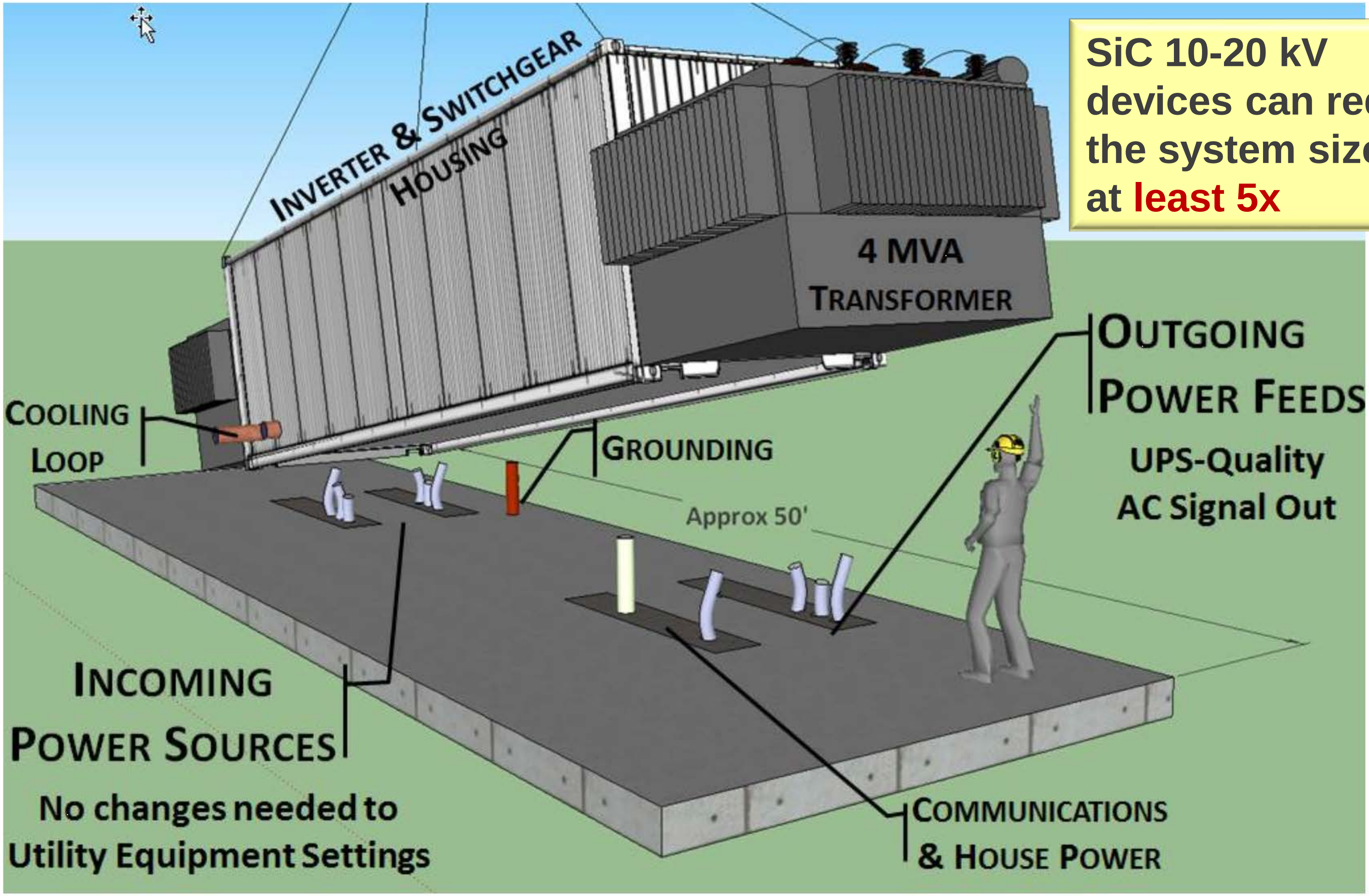
13.8 kV

640 V

Need 10-12 kV SiC power modules for a Transformerless system
- 5x smaller in size and weight

Courtesy of Dr. Allen Heffner, NIST

Pareto Energy's Grid Link System



SiC 10-20 kV devices can reduce the system size by at least 5x

http://www.paretoenergy.com/whitepaperfiles/PresentationParetoEnergyMicrogridsForDataCentersWebPageVersion.pdf

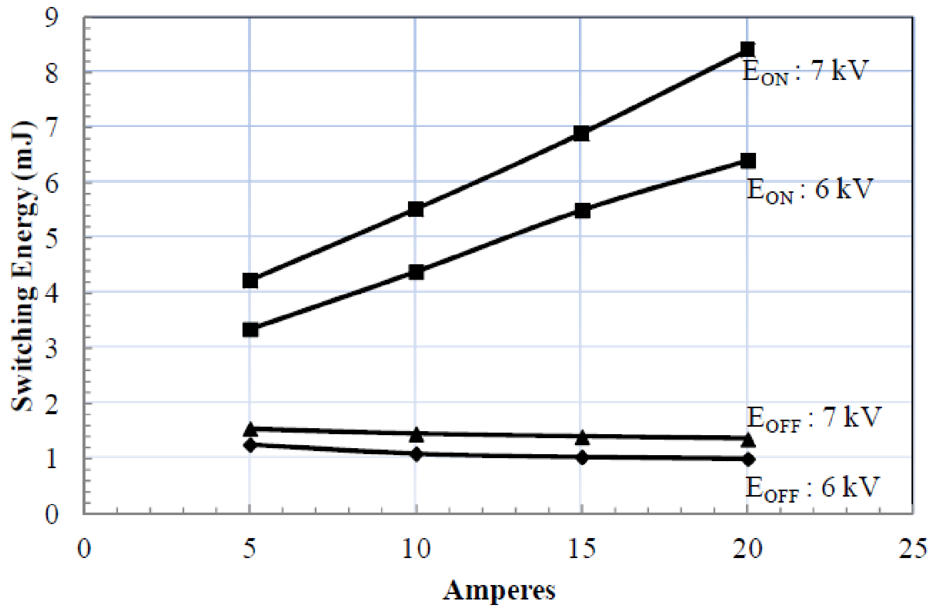
New R&D 10kV SiC MOSFETs

> 40X lower switching losses than 6.5 kV Si IGBT in boost configuration

10kV SiC MOSFET XHV-6 POWER MODULE

Device	BV	$E_{SW, TOTAL}$
SiC Gen 3 10kV SiC MOSFET	10 kV	6.5 mJ @ 6kV, 15A
Silicon 6.5kV IGBT ABB 5SMX	6.5 kV	265 mJ @ 3.6kV, 25A

Boost Configured Switching Energies

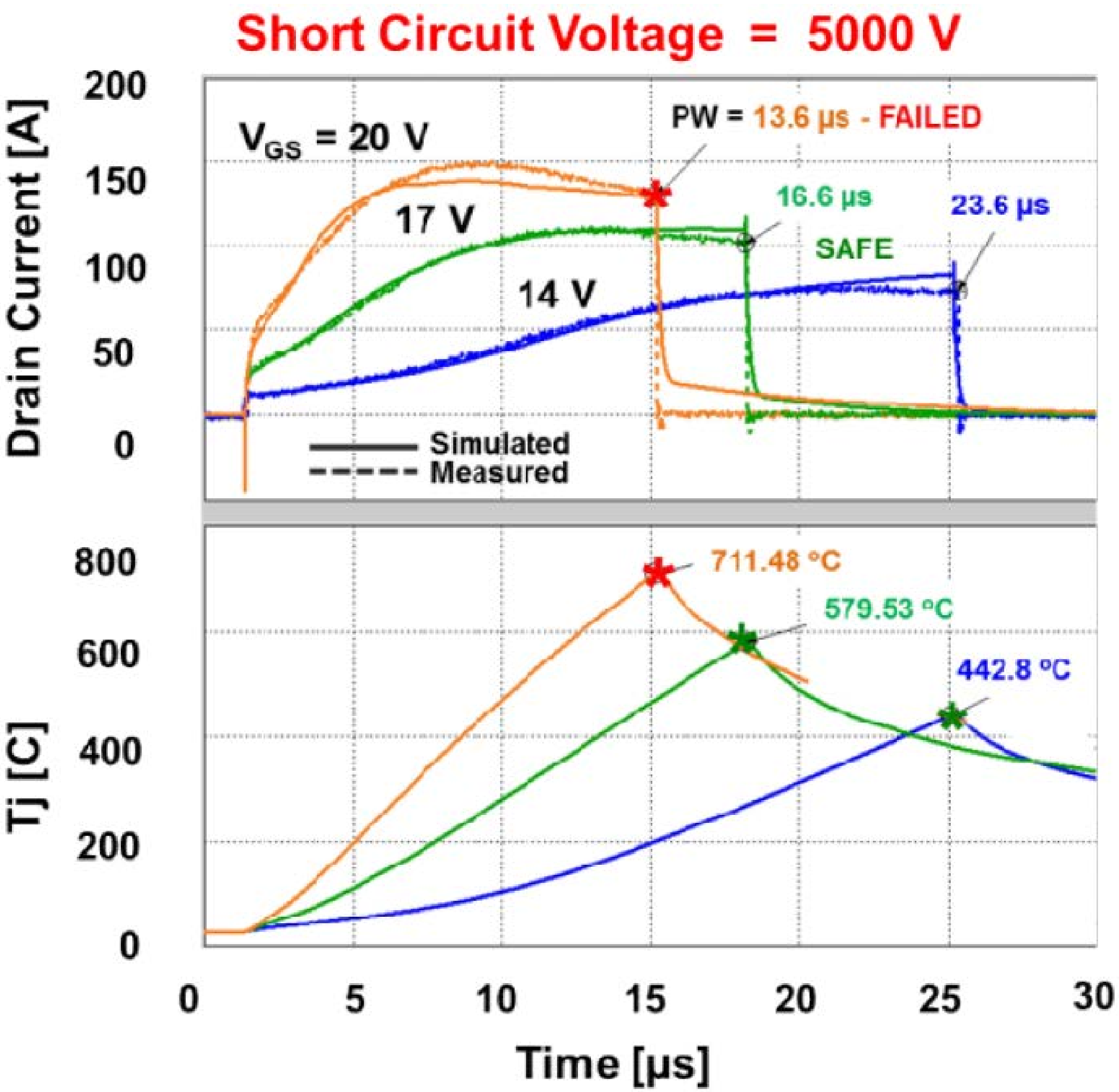


- Peak switching voltage set by overshoot and cosmic ray FIT – potentially much less de-rating in SiC vs Si

Reference: J. Casady, et al (PCIM 2015)

2. Commercial HV SiC from Wolfspeed

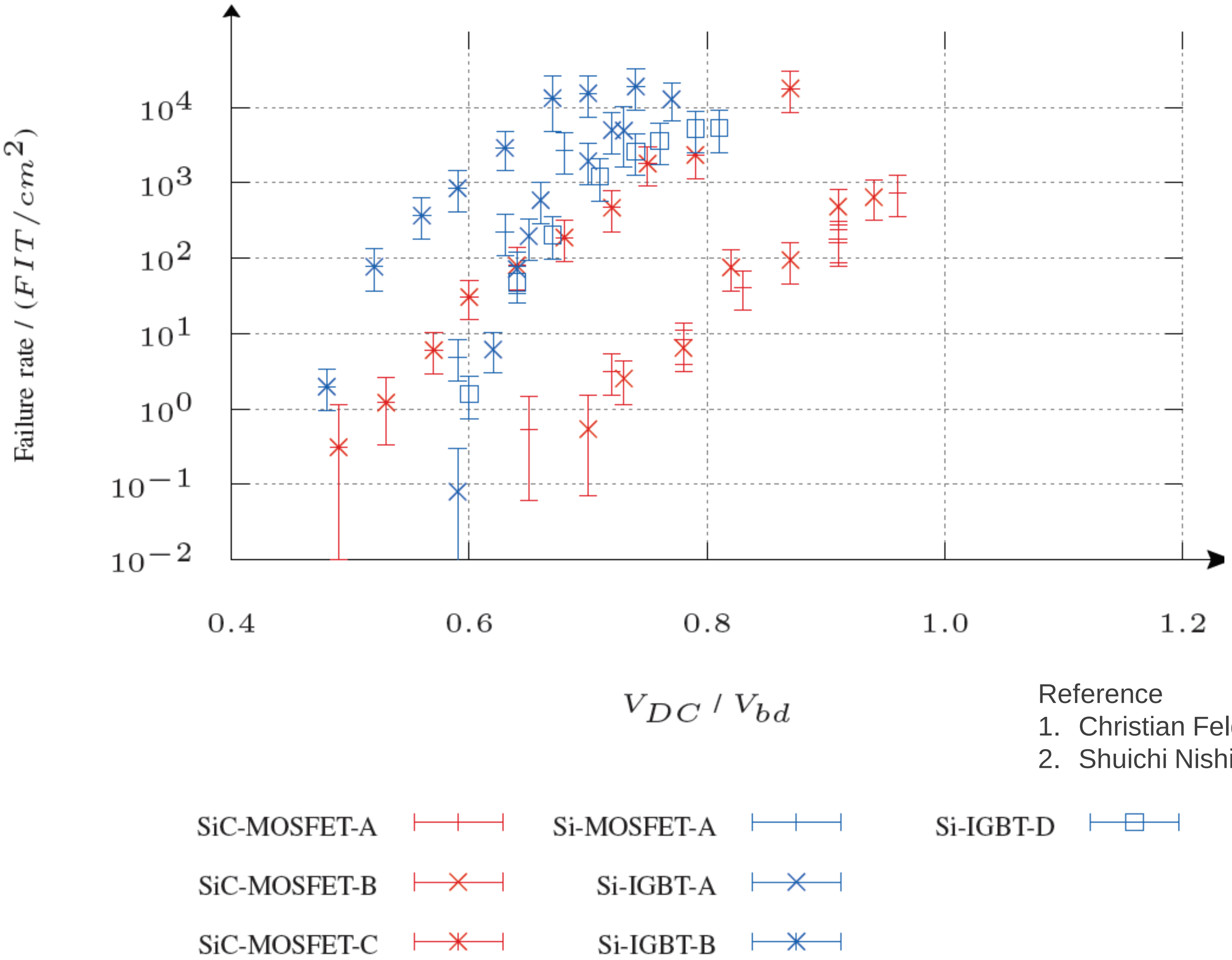
Short circuit Test of Gen 3 10kV/350mOhm



These devices are ready for insertion into commercial applications.

Price is relatively high

3. Device level issues: Si IGBTs, Si Thyristors, Cosmic Rays **De-rating required in Si devices**



Reference

1. Christian Felgemacher, et al (ISPSD 2016)
2. Shuichi Nishida, et al (ISPSD 2010)

4. Cost model for HV SiC chips

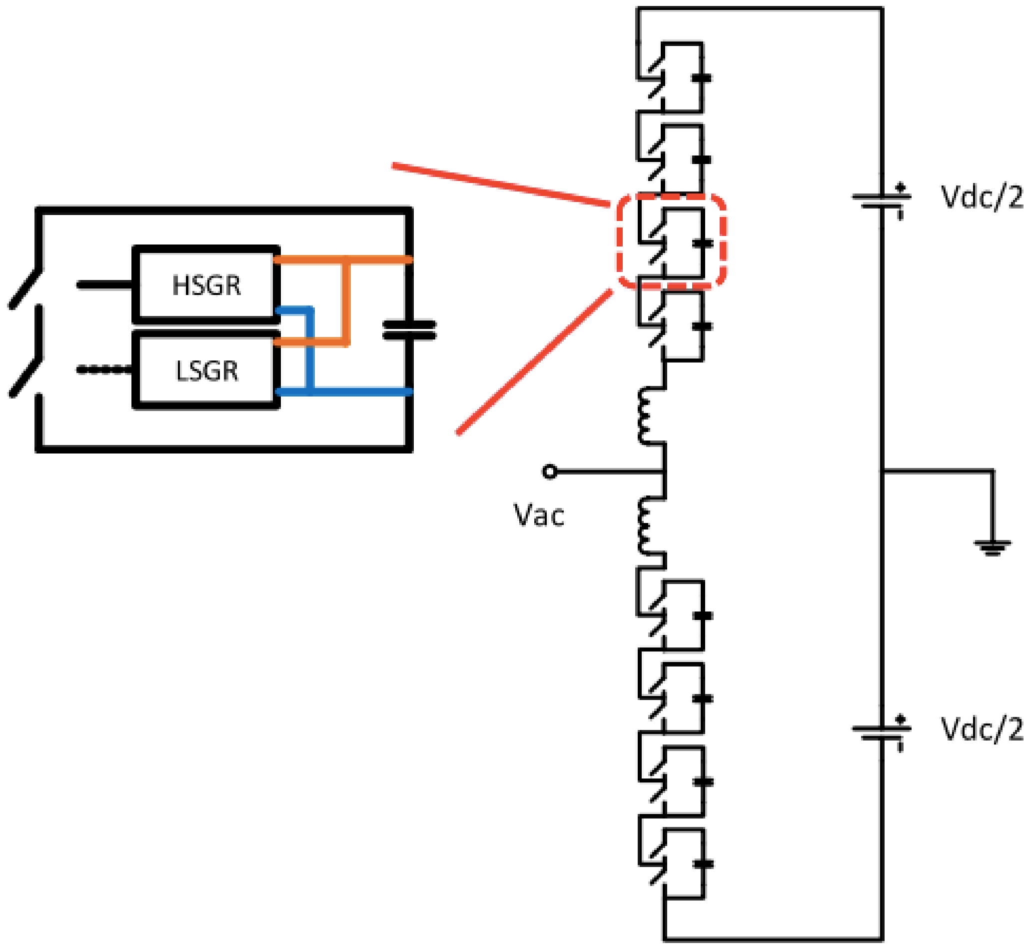
<u>Estimates of chip cost for a 12 kV/20 A MOSFET with an integrated Schottky diode</u> (chip size 8 mm × 8 mm) – Courtsey Dr. Woongje Sung at SunyPoly

	R&D Phase (2018)	Low volume (2020) 10,000 chips per year	Moderate volume (2023) 1 million chips per year
Cost per Amp	$8.7/Amp	$3.0/Amp	$1.0/Amp
Cost of 150 mm SiC substrate	$1500	$1000	$500
Cost of 120 micron thick epi	$6000	$4000	$2000
Process cost per substrate	$4000	$1600	$800
Total number of chips on a wafer excluding a 2 mm zone around the substrate	221	221	221
Yield	30%	50%	75%
Number of functional die per substrate	66	110	165
Cost per 20 A die	$174	$60	$20

5. Gate Drives for HV MMC modules

Power Harvesting for the Sub-module DC Bus

- The insulation requirement of the localized gate drive power supply is Vdc/N
- For 10 kV device, Vdc/N can be higher than 7 kV
- To implement <u>**Isolated**</u> DC/DC Converters with **7 kV** input and **15 V** output at a power less than **10 W** is challenging!

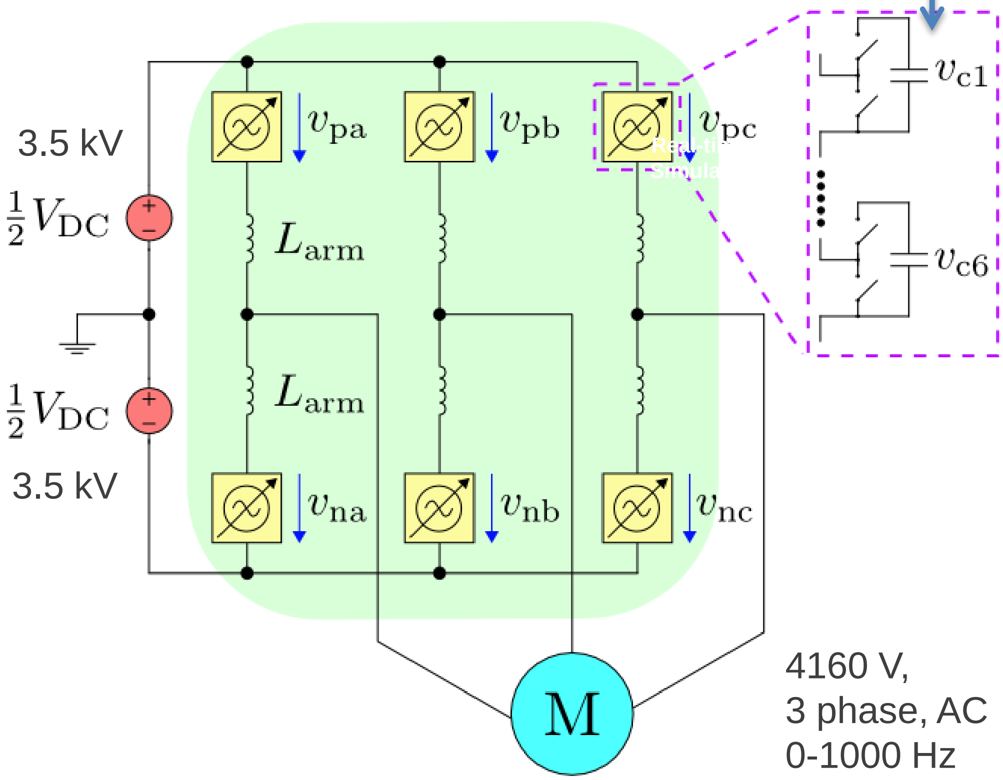


6. Development of a 1 MVA SiC-based Medium Voltage Variable Speed Drive

3-phase operational with full bus voltage of 7000 V

7-level MMC 1 MVA Converter

6, 1700 V modules
In Series



4160 V,
3 phase, AC
0-1000 Hz

* At this time, one third of the tower is populated for single phase based validations.

Tower Dimensions: 0.95 m * 0.7 m * 1.8 m = 1.2 m^3
Expected power density: 0.83 MW/m^3

Conclusions

- 10-12 kV SiC Modules are reliable, available on a custom basis and fairly expensive.
- Applications have been discouraged by high price.
- Need to have a second commercial source of HV devices and Modules.
- GeneSiC is developing 6.5 kV devices and modules.