The Scale-Up of Wide Bandgap Power Semiconductor Technology and Power Electronics

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High Megawatt (HMW) Variable Speed Drive (VSD) Technology Workshop, NIST, April 2016

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Next Generation Power Electronics (WBG) Initiative Strategy

Vision:

Capture U.S. opportunity for manufacturing leadership in:

- Wide Bandgap Power Devices (SiC- and GaN-based)
- Power Electronic Systems

Commercial Foundry

Advanced Modules

Power Electronics

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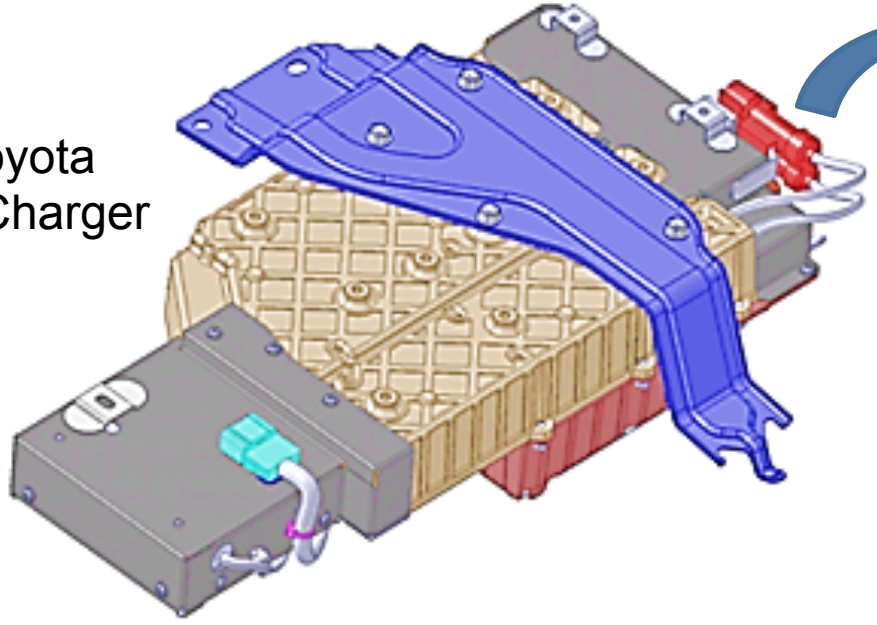
EERE Relevant Applications for WBG Semiconductors

Device Rating	Applications
200 - 600 V	Switch Mode Power Supplies Sensors for Drilling Equipment
600 - 2000 V	Solar, Wind, HVAC, Light Duty Vehicles DC Quick Charging, UPS
2 - 10 kV	Motor Speed Control (up to 10 MW), Trains, Heavy Duty Vehicles, Mining
10 - 15 kV	Motor Speed Control (10-50 MW), Process Heating, Distribution Grid Tied Renewables, Grid Storage and Server Farms

ARPAE FUNDED APEI PHEV SIC-BASED CHARGER

	Toyota Baseline	Prototype #1
Volume	387.5 in^3	52 in^3
Weight	6.6 kg	1.165 kg
Power	1 kW	6.3 kW
Efficiency	<90%	95.1%

Present Toyota
Si PHEV Charger
(1 kW)

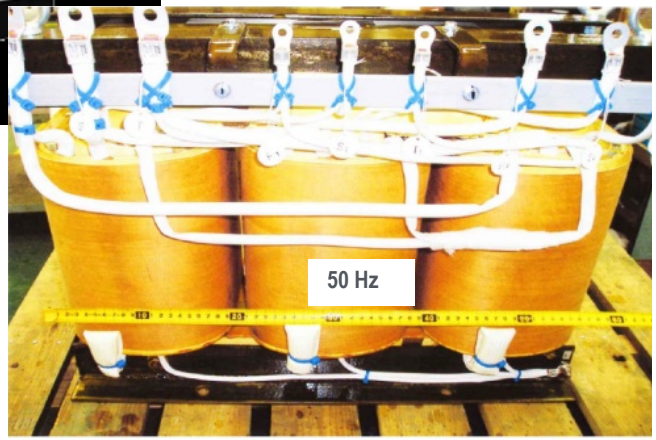


SiC
PHEV Charger
(>6 kW)

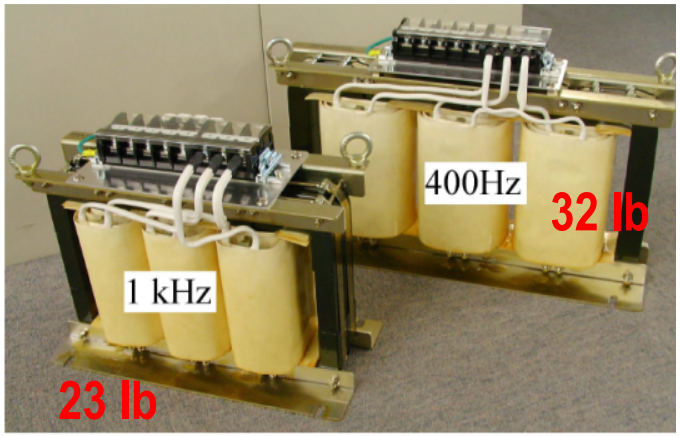
arpa·e APE International TOYOTA CREE UNIVERSITY OF ARKANSAS OAK RIDGE National Laboratory

EV Fast Chargers- Essential for EV Adoption

- 30-50 kW Charger
- Input Current: 79 A Max
- Weight: 1422 lb
- Total Capital + Operating Cost: $ 75 K



170 lb 15 kVA



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Large Power Electric Motors (1-50 MW) in COG Industry
Approx. 14% of the total electricity flows through Large Motors

- Applications in Chemical, Oil and Gas Industry (COG)
  - Hydrogen Gas Compressors (Hydro-cracking in Oil Refineries)
  - Booster Stations in NG Pipelines, High density polypropylene extruders
  - Ethylene Gas Compressors, Sea water injection and lift, etc.
- Steam, Gas Turbines and Diesel Engines for off-shore applications are being replaced by large electric motors:
  - 20-25% efficiency of off-shore installations resulting in huge CO_2 emission (230,000 tons of CO_2/year in a typical off-shore pre-compression project)

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Poor adoption of HMW, Medium Voltage Variable Speed Drives

Impact:

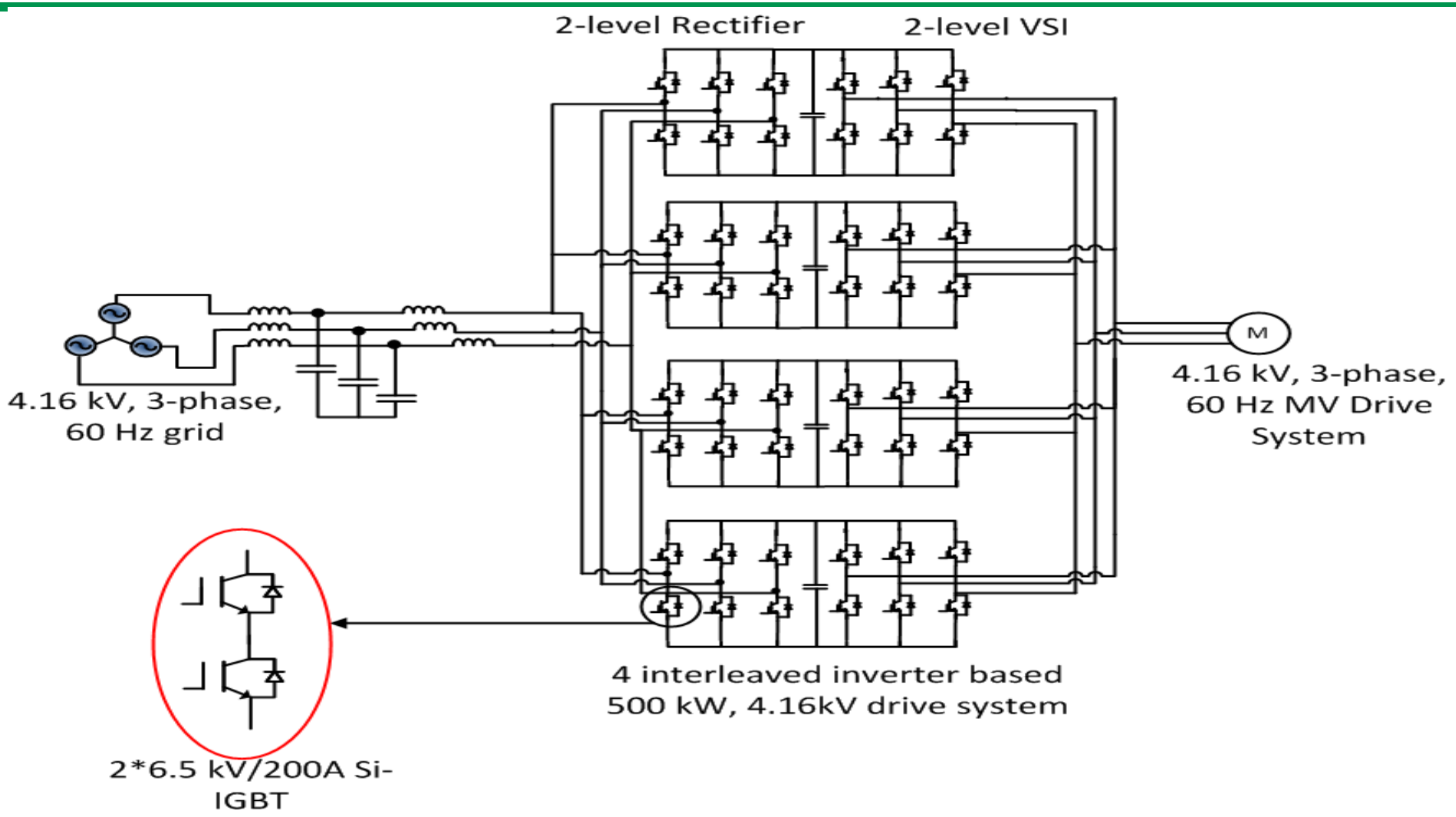
40% electricity can be saved per motor by using VSD

5% of the electricity can be saved

Barriers:

- **Initial Capital Cost of Variable Speed Drive**

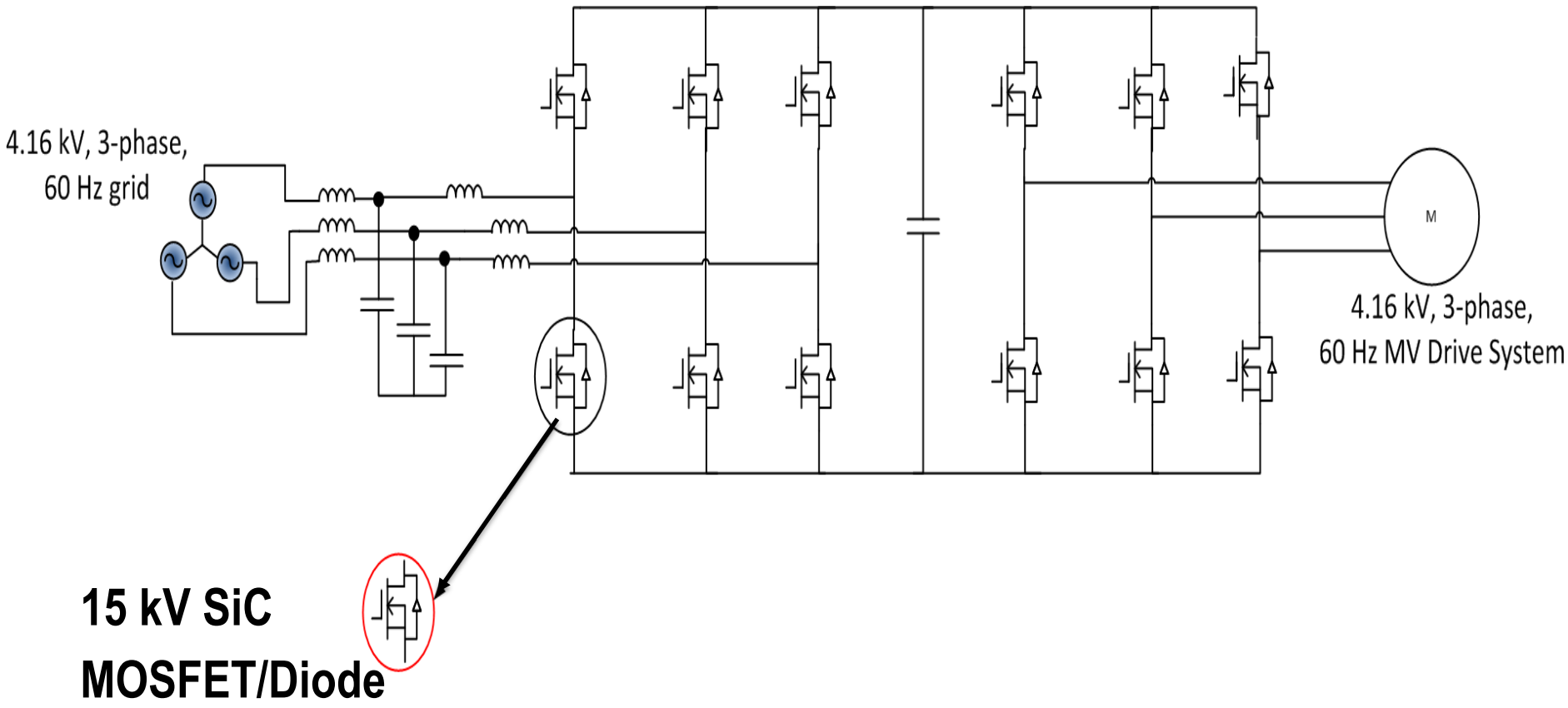
500 kW Si-IGBT based Variable Speed Drive (VSD)



4 Interleaved Inverter each switching at 400 Hz, 96, 6.5 kV Si IGBTs

Courtesy: Dr. Subhashish Bhattacharya, NCSTATE University

500 kW SiC Mosfet based drive can reduce system size



1-50 MW class motors can be reduced in size by 5x using high voltage, high freq. SiC based Variable Speed Drive (VSD) – for COG DD high rpm applications

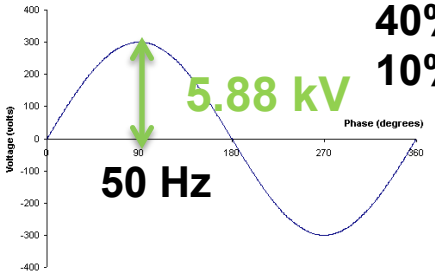
Traditional

4.16 kV
3 phase, 50 Hz
From 50 HZ
TRANSFORMER

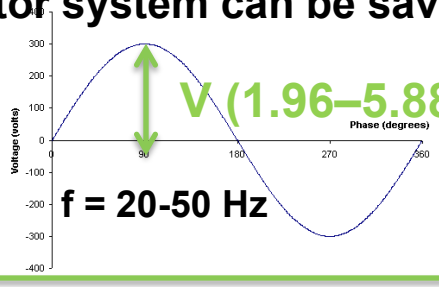
→ VSD
Si Based
Big Footprint
Expensive

→ 1-50 MW 1800 RPM Motor + Gear Box

→ High RPM Compressor Variable Speed



40% energy/motor system can be saved
10% adoption



New Approach

Delivered as one box

13.8 kV
3 phase
50 Hz

Low copper usage

High freq. Transformer + VSD, SiC Based
3x Smaller
Cheaper

→ 1-50 MW, High RPM Motor
5x smaller, GEAR BOX ELIMINATED

f = 200 – 500 Hz

→ High RPM Compressor Variable Speed

40% energy/motor system can be saved
Increased adoption

IMPACT

- VSD driven motors save 40% electricity per motor on an average by discarding mechanical throttles to control flow etc. (= > at least 5% of total electricity in US can be saved by 90% adoption of VSD)
- 5-10x reduced motor size with reduced soft and permanent magnets (rare earths) and copper.
- Reduce CO_2 emissions by replacing Gas and Steam Turbines.
- Gear Box eliminated
- 50-60 Hz transformer may be replaced by much smaller higher freq. transformer.

The Enabling Technologies:

- Wide Band Gap based Variable Speed Drives (VSD) for high voltage, high frequency and high power.
- Thin Si Steel Laminations to reduce Iron and eddy current losses.
- Manufacturing Litz wires to reduce Copper losses.
- High Speed Gears and Electromagnetic Gears.
- Aggressive cooling techniques
- High voltage insulation, dv/dt issues

Example of high speed motor

Design, Manufacture, and Testing of a high speed 10 MW Permanent Magnet Motor and Discussion of Potential Applications

10 MW motor, 4160 V, 6225 RPM, 415 Hz, 8 Pole, PM Motor Demonstration in 2006

James S. Smith, DRS

and

Andrew P. Watson, Elliott Company

Proceedings of the 35th Turbomachinery Symposium, 2006

Final Remarks

- **Assume HV SiC devices will be at cost parity with Si in 5 years from now.**
- **Full system optimization enabled by high voltage SiC power electronics – Grid connection, transformers, filters, rectifier, cooling, inverter topologies and motors.**
- **R&D and Manufacturing in US.**