Advanced Power Electronics: ONR-Funded Graduate Curriculum in Electric Energy Systems

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Structure of ONR-Funded Graduate Courses

- List of course learning objectives
- Textbook
- Video clips of each lecture
  - Approximately 30 clips each average approximately 15-20 minutes long
  - Captions
  - PowerPoint slides
  - Concept quizzes
- In-class discussion problems
- Hardware laboratory and lab manual
- On-line homework problems using Moodle
- Discussion forum
Advanced Power Electronics Topics and Contributors

1. Resonant Converters – Ned Mohan (University of Minnesota)
2. Full-bridge DC-DC Converters and Soft-Switching – Hariharan Krishnaswami (UT-San Antonio)
3. Dual Active Bridge – Amit Jain (Intel)
4. Multi-Level Converters – Prasad Enjeti (TAMU)
5. Matrix Converters - Kaushik Basu (University of Minnesota)
6. Front-End Rectifiers – Kaushik Basu (University of Minnesota)
7. Power Semiconductor Device Physics – Bill Robbins (University of Minnesota)
8. Energy-Efficient Lighting: CFLs, LEDs, IGBTs – Eric Persson (IRF)
9. Wide Bandgap Devices – Anant Agrawal (CREE)
10. Applications in Automotive Systems – Kaushik Rajashekar (UT-Dallas)
12. Magnetic Design – Bill Robbins (University of Minnesota)
13. Thermal Design – Bill Robbins (University of Minnesota)
14. EMI and EMC – Chris Henze (Analog Power Design Inc.)
15. UMN Research in High-Frequency Power Electronic Transformers, Matrix Converters
Dual Active Bridge Module

Outline
• Operating Principles
• Converter Design
• PWM Control, H-Bridge & Half-bridge combination, and Multi-Port DAB

Motivation
DC–DC converter with
• Soft-switching without auxiliary components
• Bi-directional power flow
• Galvanic isolation and/or high conversion ratio

Power Flow Between Two AC Buses
\[
\overline{V}_1 = V_1 \angle 0^\circ \quad \overline{V}_2 = V_2 \angle -\phi
\]
\[
P = \frac{V_1 V_2 \sin \phi}{\omega L}
\]
\[
\phi > 0 \quad \phi < 0
\]

Implementation with DAB

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Soft Switching Module

- ZVS turn-on – Voltage $V_{DS}$ is brought down to zero before the switch turns on.
- ZVS turn-on – Negative current before turn-on discharges $C_{ds}$ and anti-parallel diode carries current before the switch turns on.
- ZVS turn-off – Cannot guarantee zero turn-off losses, but $C_{ds}$ limits voltage $dv/dt$.

Synchronous Buck ZVS Converter
AC/AC Converters Module

Matrix Converter

- Possible switch implementation and four step commutation
- Indirect modulation: generation of adjustable magnitude and frequency PWM voltage

Back-to-Back Converter

- Space vector and carrier based PWM generator of output inverter
- Vector control of front-end rectifier
- Alternative implementations – harmonic filter
LEDs: Major New Applications Area for Power Electronics

LED Lighting Technology Benefits and Challenges

Benefits

✓ Energy efficient – compact size & less heat dissipation compared to incumbents
✓ Long lasting – electroluminescence at low input power
✓ Solid-state properties – robust, low-power operation
✓ Electronic controls – intelligence, remote operation, integration

Challenges

✓ caused by same physical reasons – solid-state devices
✓ light distribution (LID) – ill-suited for illumination high luminance, flat emitters
✓ heat dissipation – must be managed heat-sinks add challenges for LID, cost

Understanding LED Illumination

M. Nisa Khan

US Patent 8,348,467 issued to M. Nisa Khan on January 8, 2013
Semiconductor Power Device Physics and Characteristics Module

Outline

- Semiconductor Physics Review
- Power Diodes
- MOSFETS
- Thyristors and GTOs
- IGBTs
- New Materials and Devices

Cross-section of IGBT Cell

Power MOSFETs Example

- Construction of power MOSFETs
- Physical operations of MOSFETs
- Power MOSFET switching Characteristics
- Factors limiting specifications of MOSFETs
- COOLMOS or superjunction MOSFETs

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**Magnetics Design Module**

**Topics**
- Magnetic Circuits Review
- Cores and Materials
- Power Dissipation in Windings
- Eddy Currents
- Thermal Considerations
- Inductor Design Procedures
- Transformer Leakage Inductance
- Transformer Design Procedures

**Area Product Design Relationships**

\[ L I I_{\text{rms}} = k_{cu} J_{\text{rms}} B A_w A_{\text{core}} \]

\[ S = V_{\text{pri}} I_{\text{pri}} = 4.4 k_{cu} f A_{\text{core}} A_w J_{\text{rms}} B_{ac} \]
Wide Bandgap Materials and Devices Module

Outline

- Electronic properties of SiC
- SiC Schottky diodes
- SiC MOSFET
- Applications of SiC devices
- Cost savings with SiC devices
- 10-20 kV SiC devices

SiC MOSFETs & Diodes in Motor Drives

SiC MOSFETs and Si IGBTs comparison

- 1700V SiC Schottky diodes
- >10x increase in frequency
- 80% Power Savings
- 2.3% Improvement
- 1.5% Improvement
- 2.0% Improvement
- Motor Speed = 1500RPM
- 55.8% Reduction
- 53.8% Reduction

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Implementation Considerations

• Too many topics to cover in a one semester course!

• Which topics to include and which to leave out?

• First year graduate course or advanced level graduate course?

• Textbooks or reference books?

• What pedagogy to use to teach the course?

• Accompanying instructional laboratory?