Hacettepe University
Electrical and Electronics Engineering Department

ELE454
POWER ELECTRONICS

Spring Semester 2003-2004

Content:

Introduction, Power Semiconductor Devices, Loss Calculations and Cooling of Power Semiconductors, Rectifier Circuits, Converter Operation in 4-Quadrants, AC Voltage Controllers, Choppers, Inverters, Switch Mode Power Supplies, Protection of Power Converters, Applications.

Prerequisite: Electronics (ELE210)

Texbooks:

1. Cyril W. Lander, Power Electronics, Mc Graw Hill, 3rd. Ed., 1993.
2. Mohan N., Undeland T.M. and Robbins, W.P., ‘Power Electronics: Converters, Applications and Design, John Wiley and Sons, 2nd Ed., 1995.

Reference Books and Notes:

1. Power Electronics – Principles and Applications, by Joseph Vithayathil, Mc Graw-Hill, 1995.
2. Rashid M.H., Power Electronics: Circuits, Devices and Applications, Prentice Hall, 1988.
3. Bose B., Power Electronics and AC Drives, Prentice Hall, 1986.
4. Ermiş, M., Static Power Conversion I - Lecture Notes
5. Erickson, R.W., Fundamentals of Power Electronics – Lecture Notes

Goals:

This course is designed to equip seniors with knowledge about operation characteristics and major application areas of modern power semiconductor devices, and associated power converters to give them an ability to design and choose such systems for various industrial applications.

Topics:

I- INTRODUCTION *Ch.1, Text:2; Ch.1, Ref.1* (2 class hours)

Basic definitions; power electronics overview, goals of electronic power conversion; historical background, power electronics systems applications; power electronics as an interdisciplinary technology; classification of power converters.

II- POWER SEMICONDUCTORS *Ch.1, Text:1; Ch.2,28 Text:2* (7 class hours)
Summary of Ch.20-26, Text:2

2.1. General
Classification of power semiconductors, basic operating characteristics and ranges, comparison and major application areas of Power Diodes, Silicon Controlled Rectifiers (SCR or thyristor), Bipolar Junction Transistors (BJT), Power Metal Oxide Field Effect Transistors (Power MOSFET), Insulated Gate Bipolar Transistors (IGBT), Gate Turn-Off Thyristors (GTO), Insulated Gate Commutated Thyristors (IGCT).

2.2. Power diodes and SCR's
Definitions, basic structures, Power diode and SCR semiconductor physics, equivalent circuits, basic steady-state characteristics, operating regions, turn-on / turn-off behaviours, switching waveforms, snubbers, gate-cathode characteristics of SCRs: firing circuit design by the load line method, triggering process, anode-cathode (I-V) characteristics, commutation techniques.

2.3. BJT
Definitions, basic structure, output characteristics, Darlington transistor configuration, equivalent circuit, first and second breakdown effects, transistor safe operating area

2.4. Power MOSFET
Definitions, Comparison with power BJTs, Power MOSFET physics, equivalent circuit, gate parameters, output characteristics, on-state resistance, effects of temperature.

2.5. IGBT
Definitions, basic structure, comparison with Power MOSFET and BJT, equivalent circuit, output characteristics, safe operating area

2.6. GTO / IGCT
Definitions, comparison with SCR and IGBT.

2.7. Base/Gate Driver Circuits

2.8. Some Basic Switch Applications (single-quadrant, two-quadrant, and four quadrant switch realizations)

2.9. Comparison of Power Semiconductor Devices

III. LOSS CALCULATIONS AND COOLING OF POWER SEMICONDUCTORS
Ch.1, Text:1; Ch.29, Text:2 (3 class hours)

3.1. Sources of power losses in power semiconductors: forward conduction losses, switching losses, blocking-state losses
3.2. Cooling systems: basic forms of heat transfer, classification of cooling systems.
3.3. Modeling of operation at steady-state: thermal resistance concept, cooling system performance by electric circuit analogy
3.4. Modeling for operation at transient state: transient thermal impedance concept
3.5. Design of cooling systems for steady-state and pulsed operations

IV. RECTIFIER CIRCUITS (AC to DC Converters) (12 class hours)

Ch.2,3, Text:1; Ch.6, Text:2

Basics of rectifier circuits: single-phase uncontrolled/half-wave/full-wave, three-phase midpoint and full-bridge uncontrolled/half-controlled/fully-controlled circuits with different loads, principles of operation, circuit diagrams, construction of voltage and current waveforms, performance calculations: mean output voltage expressions, ripple factor, input power factor, displacement factor, overlap phenomenon, rectifier harmonics, total harmonic distortion (THD), etc… Basic definitions, assumptions and circuit nomenclature.

4.1. Performance parameters (mean output voltage, output power, efficiency, input power factor, displacement factor, ripple factor, harmonic factor, transformer utilization factor)
4.2. Single-phase half-wave rectifier circuits
   a. Uncontrolled half-wave rectifier
   b. Fully-controlled half-wave rectifier
   c. Principles of freewheeling operation
4.3. Bi-phase circuits (fully-controlled half-wave rectifier)
4.4. Single-phase bridge rectifiers
   a. Uncontrolled (single-phase diode bridge rectifier)
   b. Half-controlled bridge rectifier
   c. Fully-controlled bridge rectifier
4.5. Three-phase half-wave rectifiers (or three-phase midpoint circuits)
   a. Uncontrolled midpoint rectifier
   b. Controlled midpoint rectifier
4.6. Three-phase bridge rectifiers
   a. Uncontrolled
   b. Fully-controlled
   c. Half-controlled
4.7. Twelve-pulse circuits
4.8. Overlap phenomenon (definitions, assumptions, modelling, analysis, mean output voltage expressions)
4.9. Rectifier harmonics (voltage and current harmonics, harmonic analysis, supply aspects, load aspects)
4.10. Filtering (rectifier output smoothing, inverter output filtering, ac line filters, active filters*, electromagnetic compatibility*)

V. CONVERTER OPERATION IN FOUR QUADRANTS (2 class hours)

Ch.3, Text:1; Ch.6, Text:2

Operation in rectification and inversion modes by firing angle control of SCRs, four-quadrant operation by the use of reverse-connected converters.

VI. AC VOLTAGE CONTROLLERS (2 class hours)

Ch.6, Text:1

R, L, RL loads supplied from a single-phase/three-phase ac source via back-to-back connected thyristor pairs, circuit diagrams, principle of operation, rms value of load voltage.

VII. CHOPPERS (DC to DC Converters) (3 class hours)

Ch.7, Text:2

Basic dc-dc converter power circuits, operating principles, and converter analysis

7.1. Classification of dc-dc converters
7.2. Voltage step-down chopper: buck converter
7.3. Voltage step-up chopper: boost converter
7.4. Step up/down chopper: buck-boost converter

VIII. INVERTERS (DC to AC Converters) (4 class hours)

Ch.5, Text:1; Ch.8, Text:2

8.1. Functions and features of inverters, inverter applications
8.2. Basic types of inverters: voltage-source, current-source inverters
8.3. The voltage-source half-bridge inverter
  a. Operation without pulse-width modulation (without PWM)
  b. Control of AC frequency and AC voltage
  c. Sinusoidal pulse width modulation (SPWM), output waveform considerations
8.4. The voltage source full-bridge inverter
  a. Operation without PWM
  b. Control of AC output voltage by PWM, voltage harmonics
  c. Shaping of output voltage by SPWM
  d. Implementation of SPWM in a single-phase full-bridge inverter
8.5. The three-phase voltage source inverter with Y or Δ connected loads
8.6. The three-phase current source inverter

IX. POWER SUPPLIES (SMPS) (3 class hours)

Ch.10, Text:2; Sec.6.10, Text:1

Introduction: Linear vs Switch-Mode Power Supplies (SMPS), functional circuit blocks of an 'off-line' switcher, an overview of basic SMPS converter topologies: buck, boost, forward, flyback, push-pull, half-bridge, full-bridge configurations, comparison of common PWM switching regulator topologies, methods of control: voltage-mode, current-mode controls, soft-switching methods: quasi-resonant converters (ZVS, ZCS concepts), resonant converters*.

X. PROTECTION OF POWER CONVERTERS (2 class hours)

Ch.10, Text:1

Protection against line voltage transients, overload, faults, such as transient voltage suppressors, snubbers, semiconductor fuses, chokes, capacitors. Safety margins in semiconductor device selection.