EN 206 - Power Electronics and Machines

Introduction

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Syllabus

- Single phase and three phase transformers, autotransformers
- Characteristics of power semi conductor switches
- AC to DC converters
  - Phase Controlled Converters
  - Unity power factor converters (VSI and CSI)
- DC-DC Converters
  - Operation of Buck, Boost, Buck-boost, Cuk, Flyback and forward converters
- Basic concepts of Electromechanical energy conversion leading to rotating machines
- **Mid Semester Exam**

Syllabus

- Principle of operation characteristics and control of DC machine
- DC-AC Converters
  - Single phase and three phase topologies
  - PWM topologies: Space Vector PWM, Sine triangular PWM
- Induction Machines
  - Principle of operation, characteristics and control
- Synchronous Machines
  - Principle of operation, characteristics and control
- AC-AC conversion
- Special machines: Stepper motor, brushless DC motor
- Application of power electronic systems (HVDC, active power filters, motor control)
- **End Semester Exam**

Lecture Organization - Modules

- Introduction and Power Semiconductor Switches
- Module 1: Transformers
- Module 2: AC/DC converter / Rectifier
- Module 3: DC machines and Drives
- Module 4: DC/DC converter
- Module 5: Induction Machine
- Module 6: DC/AC converter / Inverter
- Module 7: AC/AC converter / Cyclo converter
- Module 8: Synchronous Machine
- Module 9: Special Topics: Machines, HVDC, APF

Course Page

- A course page is created for EN 206.
- Link will be posted in moodle.
- All updates will also be available on this page.
- In addition to slides, reading material, links sample exam papers will be posted on this page.

Course Page - Sample

Lecture schedule

EN 206 Spring 2012

Updated: 03-1-12.
Tentative lecture schedule for EN 206.
The lecture dates and quiz dates are subjected to change. All announcements shall be made on course page.

Wednesday	Friday
Lecture -1, 4-Jan-2012 Introduction, Power Semiconductor Switches Lecture Slides	**6-Jan-2012** Tech Fest
Lecture -2, 11-Jan-2012 Transformers - Principle of operation, equivalent circuit Lecture Slides "http://www.ese.iitb.ac.in/~suryad/lectures/Lecture-1.pdf"	**Lecture -3, 13-Jan** Transformers - Testing (SC/OC Test) Lecture Slides
Lecture -4, 18-Jan-2012 Transformers - Three Phase Transformer Lecture Slides	**Lecture -5, 20-Jan-2012** AC-DC Converters: Uncontrolled rectifier (single and three phase), ripple fa Lecture Slides
Lecture -6, 25-Jan-2012 AC-DC Converters: Controlled rectifier- single phase with R and RL load Lecture Slides	**Lecture -7, 25-Jan-2012** AC-DC Converters: Controlled rectifier- three phase with R and RL load Lecture Slides
Lecture -8, 01-Feb-2012 AC-DC Converters: Three phase PWM rectifiers, UPF Lecture Slides	**Lecture -9, 03-Feb-2012** DC Machines: Principle of operation of DC motor and generator Lecture Slides

Application(s) - Machines

Transformers

- Key role in transforming power
- Impedance matching
- Step up/down voltage

DC Machines

- CD Players
- Locomotive
- Paper Mills

Induction Machine

- Ceiling fan
- Industrial loads
- Wind power generation

Synchronous Machine

- Thermal Power Plants (High Speed)
- Hydro Power Plants (low speed)

Application(s) - Converters

AC/DC Converter

- Power Supply
- Charger(s)
- Electronic Choke

DC/DC Converter

- Computer power supply
- MPPT
- Ship board power systems

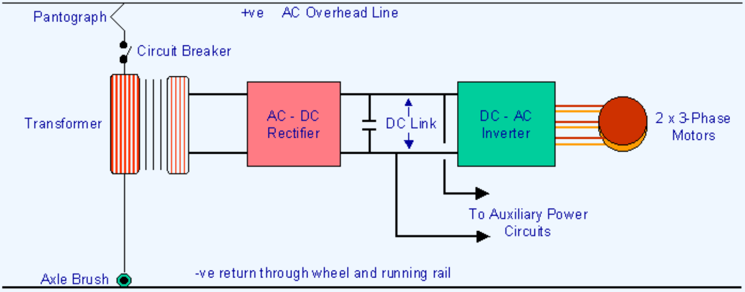
DC/AC Converter

- Power Conversion
- Speed control of Motors
- Back up power supply

AC/AC Converter

- Frequency conversion
- Power electronic transformer

Electric Locomotive

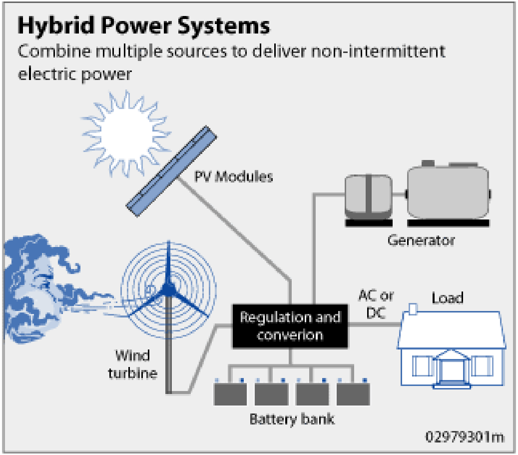


Schematic of single phase AC supply powering 3-phase AC motors

[1] Electric Locomotive supplied by single phase supply

[1]Ref: http://www.railway-technical.com/tract-02.shtml

Hybrid System



[2] Solar PV-Wind Hybrid Energy System

[2]Ref: http://wikipedia.org

Basics of Electromagnetism

- Like poles repel and unlike poles attract
- Magnetic lines of force
  - Form closed loop
  - Cannot intersect
  - Always in a state of tension.
- A piece of soft iron placed in a magnetic field is temporarily magnetized by induction.
- Magnetic field around a conductor
- Magnetic field around a coil
- Electromagnetic induction
- Force on current carrying conductor in magnetic field

Analogy - Electricity & Magnetism

Electricity		Magnetism	
Parameter	Units	Parameter	Units
EMF	volt	MMF	ampere-turn
Current	ampere	Flux	weber
Resistance	ohm	Reluctance	ampere-turn/weber
Conductance	mho	Permeability	henry/m

Reluctance: It is a measure of the opposition offered by a magnetic circuit to the setting up of flux (mm/flux).

Permeance $= \frac{1}{Reluctance}$

Permeability$(\mu) = \frac{B}{H}$

H is the magnetic field strength (mmf per unit length)

Hysteresis

- Remanence : is a kind of friction force resisting movement of the magnetic domains. The material is magnetized and retained flux density
- The ability of ferromagnetic material to retain residual magnetism is termed as its retentivity
- The magnetic force required to reduce the remanence to zero is termed as coercive force
- The B/H loop demonstrates that some energy is absorbed into a magnetic core to overcome the friction involved in changing the alignment of the magnetic domains.
- A core that is subjected to repeated and rapid reversals of the magnetic field may absorb a lot of energy which results in heating of the core and resulting in lost energy.
- Area enclosed by hysteresis loop is proportional to the lost energy

Eddy Currents

- Changing magnetic field induces a voltage in a conductor placed within that field.
- Eddy currents cause heating of the core
- Eddy currents exist even if the core is non magnetizing but electrical conductor
- Use of laminations reduce eddy current losses
- Surface of laminations are varnished or thinly insulated on either side so that they offer a high resistance to the flow of circulating eddy currents.

Types of Semiconductor Switches

There are three type of semiconductor switches:

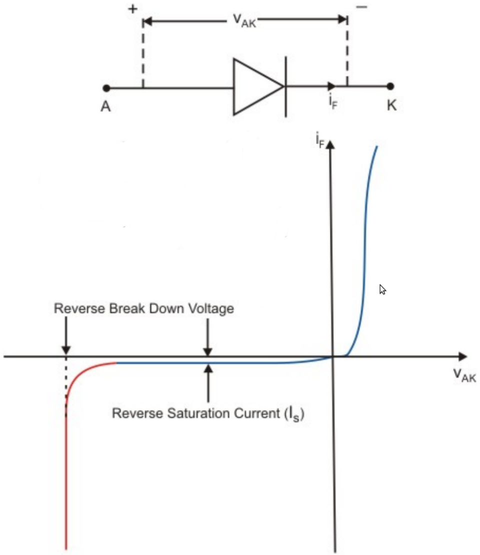
- Uncontrolled switch
  - On and Off state are controlled by circuit parameters. Ex: Diode
- Semicontrolled switch
  - On or Off state is controlled by applying an external signal. Ex: Silicon Controlled Rectifier or Thyristor, GTO
- Fully Controlled switch
  - On and Off state are controlled by circuit parameters. Ex: BJT, IGBT, MOSFET

Selection of a semiconductor switch is based on the control requirement.

Diode

- Diode is forward biased when Anode voltage is higher than Cathode voltage ($V_{ak} > 0$). Current flow is because of both majority and minority carriers.
- Diode conducts in forward biased mode and the current is decided by the load connected.
- The forward bias voltage is 0.7 for normal/signal diodes and 1.5 for power diodes.
- An ideal diode characteristics lie on X-Y axis. It can carry current of (I_{rated}) and block voltage of (V_{BD}).

Diode Characteristics



Diode Parameters

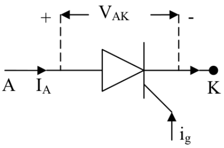
- Average forward current (maximum)
- Conducting losses
- Reverse blocking voltage (V_{BD})
- Surge current
- Reverse recovery time (t_{rr})

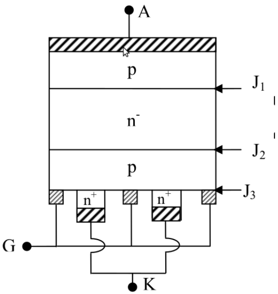
Type of Power Diodes

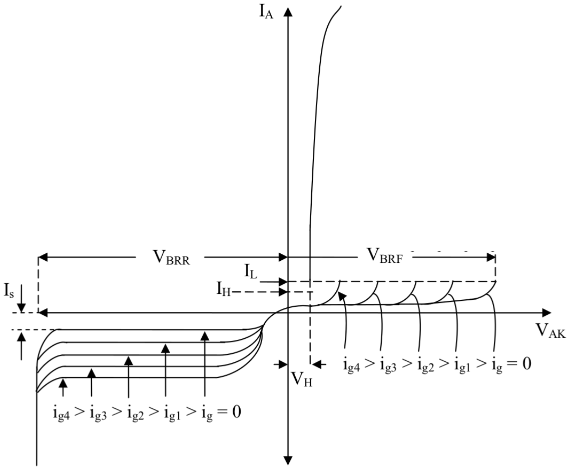
- Rectifier Diodes
  - Line frequency applications, available at high voltage and current ratings (4500A, 6000V)
- Fast Recovery Diodes
  - High frequency applications, available at high voltage and current ratings (1100A, 4500V), t_{rr} is of the order of $< 1\mu$ sec
- Schottky Diodes
  - Very low voltage drop during on state, available at voltage and current ratings (300A, 100V)
- Silicon Carbide Diodes
  - Very high fast switching, Very low power loss (ultra low), but very expensive.

Silicon Controlled Rectifier (SCR)- Thyristor

- It is a three terminal (anode, cathode, gate), four layer device (p-n-p-n). It has three junctions (j_1,j_2 and j_3)
- When the device is forward biased and there is a leakage current in the device then it is said to be in forward blocking mode.
- When the voltage applied is higher than the forward break over voltage (V_{BO}) then the SCR conducts.



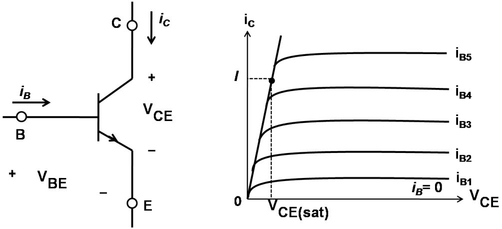



I_A
V_BRR
V_BRF
I_L
I_H
I_s
V_AK
V_H
i_g4 > i_g3 > i_g2 > i_g1 > i_g = 0
i_g4 > i_g3 > i_g2 > i_g1 > i_g = 0

Silicon Controlled Rectifier (SCR)- Thyristor

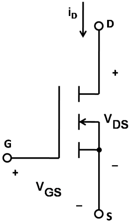
- A gate pulse (positive) will move the device from forward blocking to forward conducting mode.
- Higher the gate current, lower will be the voltage applied across the device. The gate current reduces the depletion layer around junction J_2
- Once the device current is higher than the latch current (I_L), the gate signal has no control over the device.
- The device will stop conducting when the current through the device is less than holding current (I_H)
- The SCR may go into conduction for large value of dv/dt, higher temperature across the device. It is also possible to move thyristor into conduction mode using light.

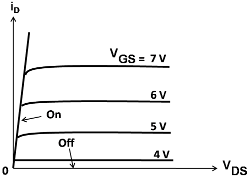
Bi-polar Junction Transistor (BJT)

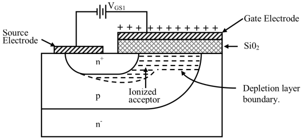


- BJT is a current controlled device.
- Base current must be supplied continuously to keep them in on state.
- Typical switching times are in the range of few hundred nano seconds to a few microseconds.
- Generally used in linear region (linear amplifiers).
- On state loss is less compared to MOSFET. Excellent ON state characteristics.

Metal Oxide Semi conductor Field Effect Transistor (MOSFET)







- It is a voltage control device. It requires continuous application of a gate source voltage of appropriate magnitude in order to be in on state.
- The switching times are very short, being the range of a few tens of nanoseconds to a few hundred nanoseconds depending on the device type.
- On state resistance between drain and source is high. More losses compared to BJT.

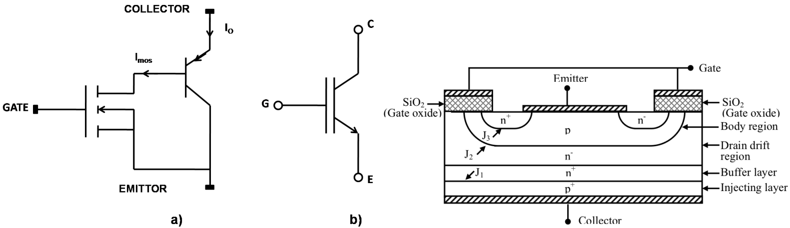
MOSFET

- It has an antiparallel body diode.
- 300- 400V MOSFET compete with bipolar transistors only if the switching frequency is in excess of 30-100KHz.
- Available in voltage ratings $> 1000V$ but small current ratings 100A with small voltages
- Excellent turn off characteristics because of only majority carriers.
- Parallel operation is easy

Comparison - BJT and MOSFET

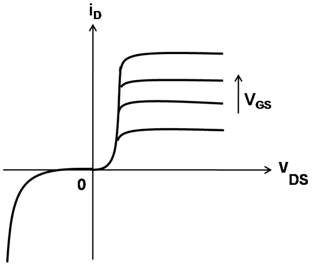
- BJT is a bipolar device and MOSFET is unipolar device.
- Input impedance of BJT (kilo ohm) is low while MOSFET has high input impedance (mega ohm).
- At higher voltage ratings MOSFET have more conduction loss.
- MOSFET has excellent turn-on and off characteristics.
- MOSFET is a voltage controlled device while BJT is a current controlled device.
- Parallel operation of MOSFET is possible because of positive temperature coefficient while it is difficult with BJT.
- MOSFET has lower switching and more conduction losses while BJT has higher switching and lower conduction losses. MOSFET is a good choice for high frequency applications and BJT for low frequency applications (10Hz -10kHz).

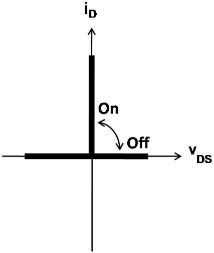
Insulated Gate Bipolar Transistor (IGBT) - Jayant Baliga (1983)



- It combines the property of MOSFET and BJT.
- IGBT has a high impedance gate, which requires only a small amount of energy to switch the device - MOSFET.
- Small on stage voltage even in devices with large blocking voltage ratings - BJT.

Insulated Gate Bipolar Transistor (IGBT)





- Presence of minority carriers, there is an increase in turn-off time.
- Can be designed to block negative voltages - GTO
- Turn-on and turn-off times on the order of 1 micro second
- Module ratings as large as 1700V and 1200A

Comparison -MOSFET and IGBT

- Current flow is because of majority carriers in MOSFET while it is beacause of both majority and minority carriers in case of IGBT.
- Because of poor turn off properties of IGBT when compared to MOSFET, IGBTs are used for low frequency applications.
- Both are voltage controlled devices.
- With rise in temperature ON state voltage drop and hence loss are higher in MOSFET when compared with IGBT.
- Both IGBT and MOSFET have high input imdendance.

Summary

- Course introduction, review of basic concepts, power switching devices.

Next Class

- Transformers
  - Principle of operation
  - Equivalent Circuit
- Thank you!!

For Further Reading:

- "Power Electronics: Converters, Applications, and Design" Ned Mohan, Tore M. Undeland, William P. Robbins, Wiley
- "Elements of Power Electronics", Philip. T. Krien, Oxford Series