EEL 646 POWER ELECTRONICS II

Issa Batarseh

January 13, 2015

Agenda

- About the course
- Syllabus Review
- Course Topics
- Review of Power Electronics I
- Questions

CLASS SYLLABUS
Spring 2015

POWER ELECTRONICS II
EEL 6246

Instructor: Issa Batarseh
Office: HEC 204
Office Hours: T 1:15 - 2:15 PM
Th 10:00 -12:00PM (150 University Towers – Research Park)

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Class Room: BA1 216A

Recommended Textbook: POWER ELECTRONIC CIRCUITS, by Issa Batarseh

Handouts

Course Description: Advanced topics in power electronics, soft-switching techniques, small signal modeling of PWM and resonant converters, control techniques, power factor correction circuits.

Introduction (cont'd)

Recommended Textbook:	POWER ELECTRONIC CIRCUITS, by Issa Batarseh
	Handouts
Course Description:	Advanced topics in power electronics, soft-switching techniques, small signal modeling of PWM and resonant converters, control techniques, power factor correction circuits.
Course Objectives:	The objective of the second course in power electronics is to introduce the students to advanced topics in *power electronics*. The soft-switching techniques which includes the zero-voltage-switching and zero-current-switching will be covered. The students will learn how to model and obtain the small signal responses for the dc-to-dc switch-mode converters and resonant converters. If time permits, the course will cover recent topologies in power factor corrections.
Prerequisites:	Power Electronics I (EEL 5245) or consent of the Instructor.
Credit Hours:	3
Homework:	Homework assignments will be based on course handouts given by the instructor.

Introduction (cont'd)

Project: Each student will be required to choose a topic form a technical journal, and submit 10 to 15-page report at the end of the semester. You may select any IEEE Transaction paper in power electronics. This project carry 30% of the final grade. **Student will be required to present their project in the class.**

Topics:

- Resonant Converters: (Chapters 6 and handouts)
  - Series and Parallel Resonant Converters
  - Soft-switching in power converters:
    Zero-voltage-switching (ZVS),
    Zero-Current-switching (ZCS)
    Zero-Voltage and Current-Transitions (ZVT & ZCT)
    Soft-switching applications in inverters and LED Drivers.
- Dynamic modeling and Control of PWM converters (Chapter 10 unpublished - Handout).
- PWM Small Signal modeling
- Power Factor Corrections

Course Content:

Engineering Design:	1 credit hours
Engineering Science:	2 credit hours

Introduction (cont'd)

Grading:	Exam I	30%
	Final	40%
	Project & Presentation	30%

		100%

Student Academic Activities:

As of Fall 2014, all faculty members are required to document students' academic activity at the beginning of each course. In order to document that the course has begun, instructor will take attendance in the first week of classes, or as soon as possible after adding the course. Failure to do so will result in a delay in the disbursement of student's financial aid.

For more info, please visit:

http://teach.ucf.edu/support/

What is Power Electronics?

- Electronics: Solid State Electronics Devices and their Driving Circuits.
- Power: Static and Dynamic Requirements for Generation, Conversion and Transmission of Power.
- Control: The Steady State and Dynamic Stability of the Closed Loop system.

POWER ELECTRONICS may be defined as the application of Solid State Electronics for the Control and conversion of Power.

Historical Perspective

- Traditional power conversion
  - Linear Electronics- Transistors in active mode (linear region)
    - Transistor acts as variable resistor for control
    - Terrible efficiency (50% not uncommon)
    - Low conversion range (greater Vd smaller efficiency)
    - Low power applications
  - Motor-Generator Sets (AC-DC or AC-AC)
    - Can still be found in use
    - Large physical size
    - Maintenance intensive
    - Low efficiency
    - Poor Load regulation

Modern Power Electronics

- Can have efficiencies approaching 100%

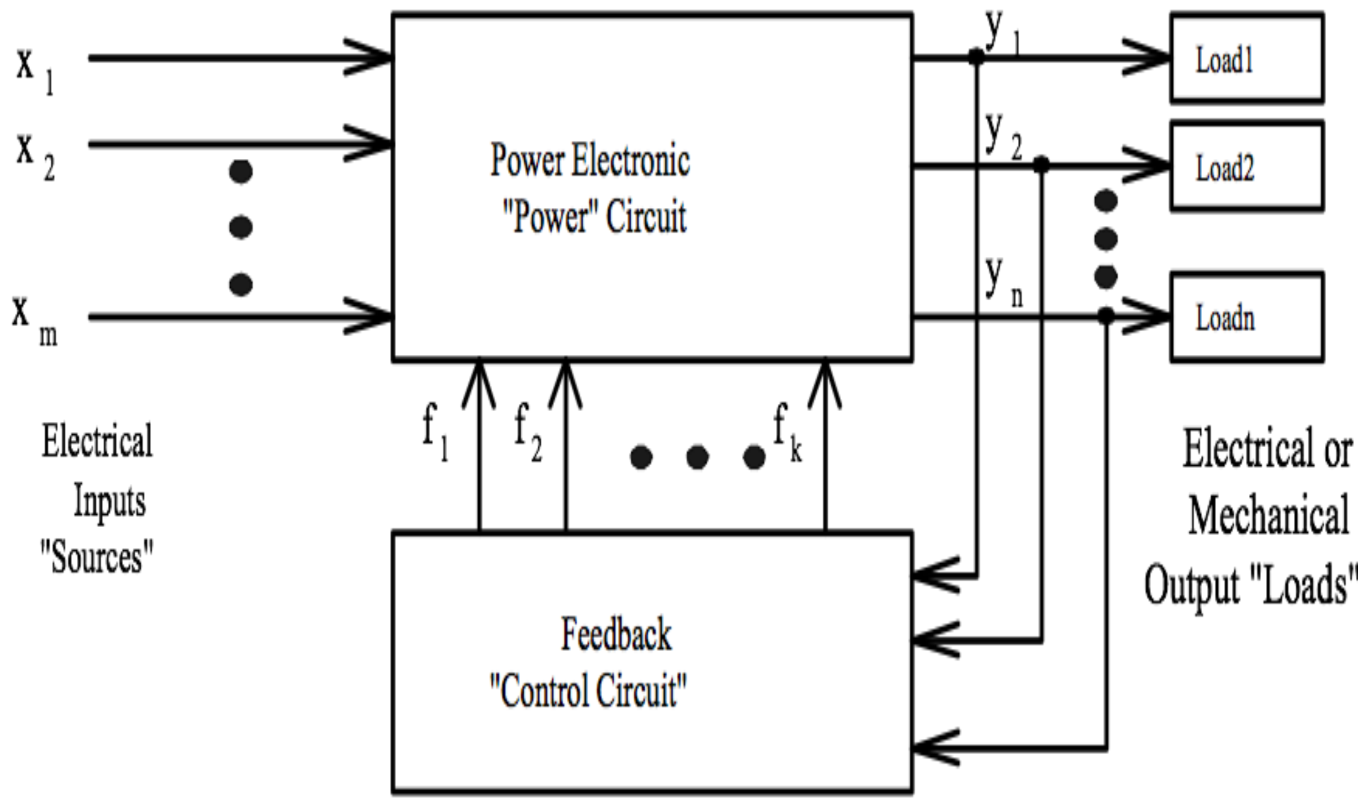
  Uses switches in saturation mode (On of Off)

  On state-resistance can be down in tenths of Ohms
- Are much smaller than predecessors

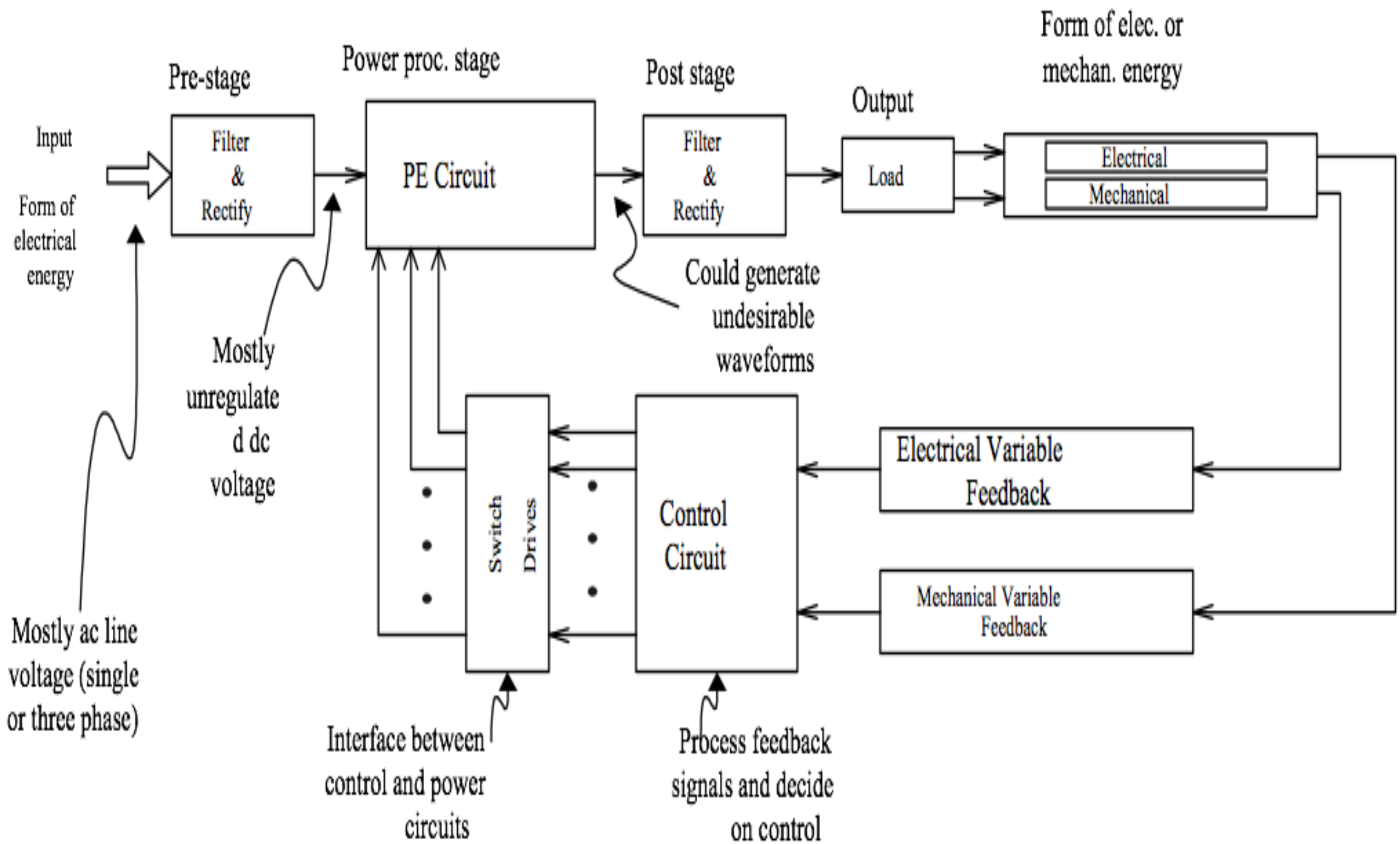
  High switching frequency means smaller magnetic components.

  Reduced losses means smaller package size
- Net effect is better efficiency, greater power density (10’sW/ in^3 attainable)

Simplified Block Diagram of a Power Electronics System



Detailed Block Diagram of Power Electronics System



Multidisciplinary Nature of Power Electronics

- Power electronics is comprised of:

  Semiconductor Devices

  Analog Circuits

  Control Design

  Magnetics

  Electric Machines

  Power Systems Engineering

  Circuit Simulation

Power Electronics
Focus Areas

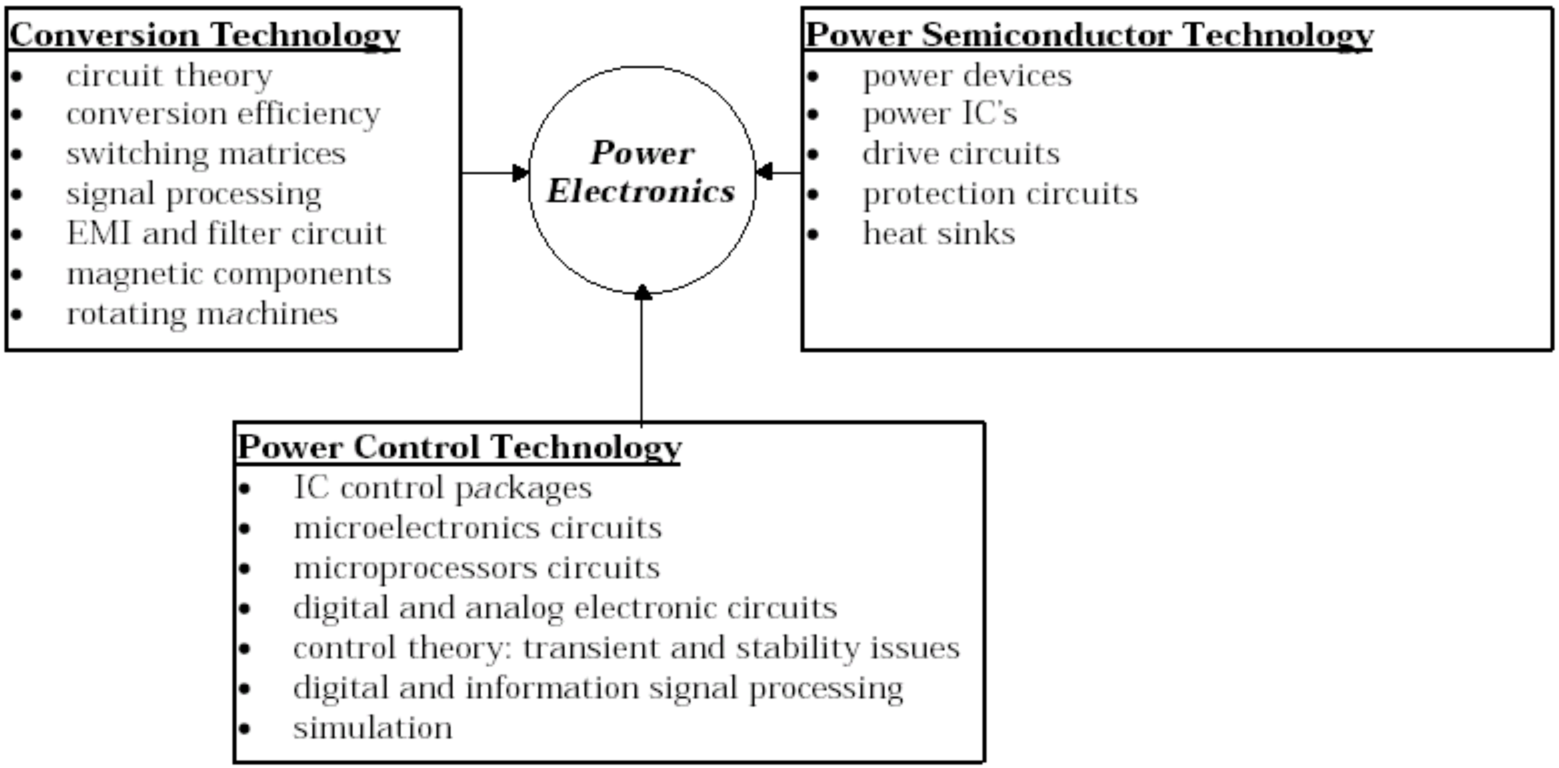


Fig. 1.1 Power Electronics encompasses three Technologies: Conversion, Power Semiconductor, and Power Control Technologies

Power Conversion Dictates
Change in Current and/or Voltage:

- Voltage/Current form ***ac*** or ***dc***
- Voltage/Current level (magnitude)
- Voltage frequency (line or otherwise)
- Voltage/Current waveshape (sinusoidal or nonsinusoidal such as square, triangle, sawtooth, etc.)
- Voltage phase(single or three-phase).

Conversion Type Description

Power Electronic systems perform one or more of the following conversion functions:

a)Rectification (***ac***-to-***dc***)

b) Inversion (***dc***-to-***ac***)

c) Cycloconversion

(***ac***-to-***ac*** different frequencies) or

(***ac***-to-***ac*** same frequency)

d) Conversion (***dc***-to-***dc***)

Figures of Merit for Power Electronic Converters

- What is the objective?

  Overall goal: To produce a converter that performs well in these areas:

  Efficiency

  Transient Response

  Load and Line Regulation

  Power Density

  Input/Output Distortion (Input Power Factor)

  Reliability (MTBF)

  Cost

  In the final analysis, the job is to process and control the flow of electric energy by supplying currents/voltages in a form most suited to both the load and energy source

Industrial Applications

Solar Energy Conversion (PV)

SMPS

PFC

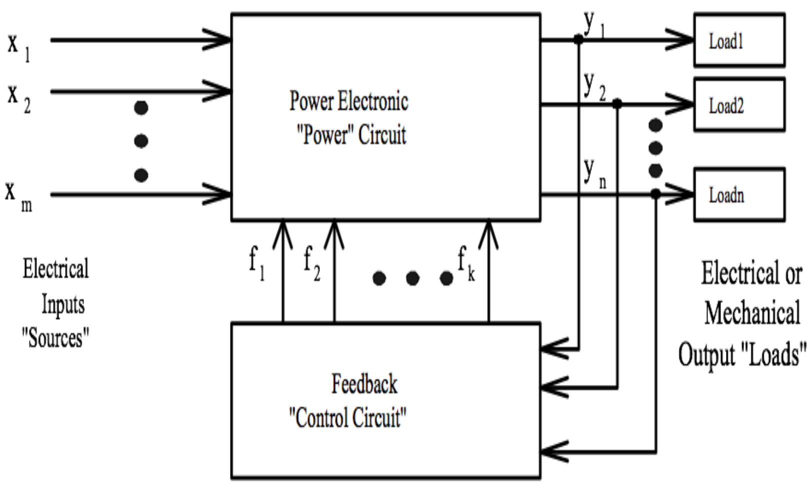
Soft-Switching converters

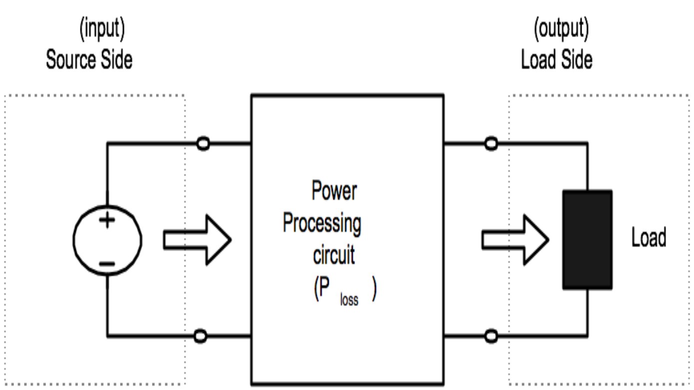
LED Drivers

Uninterruptible Power Supplies

Motor Drives

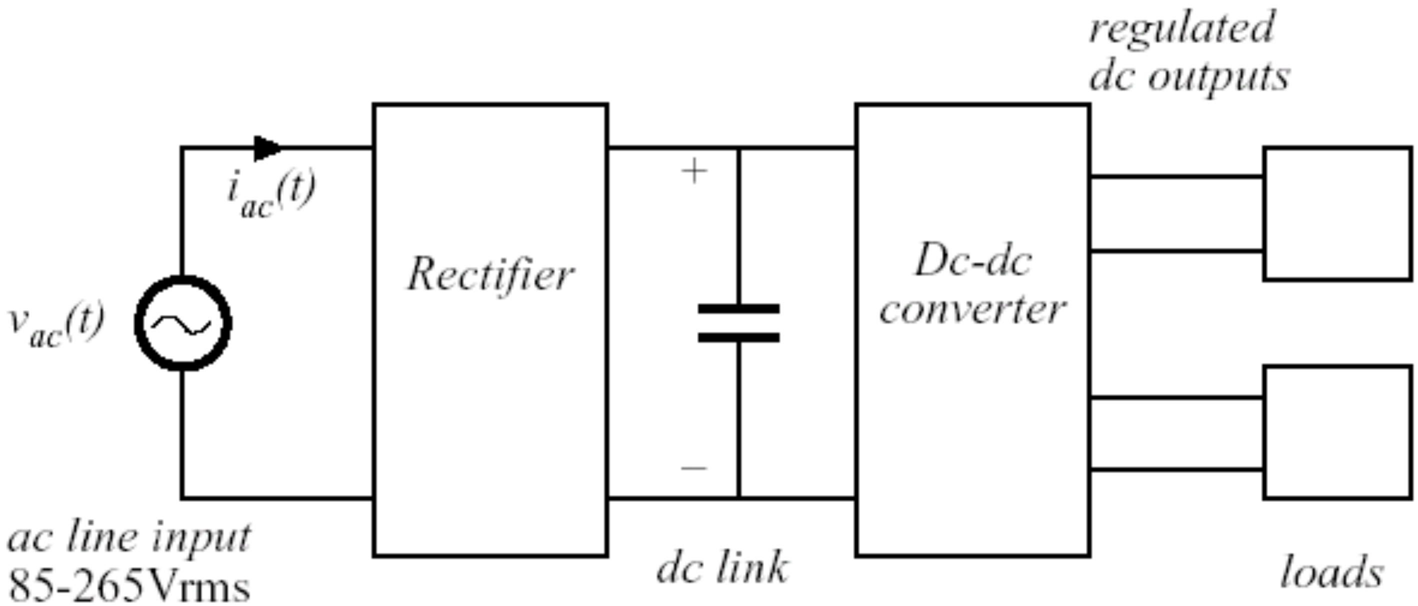
Over All Block Diagram



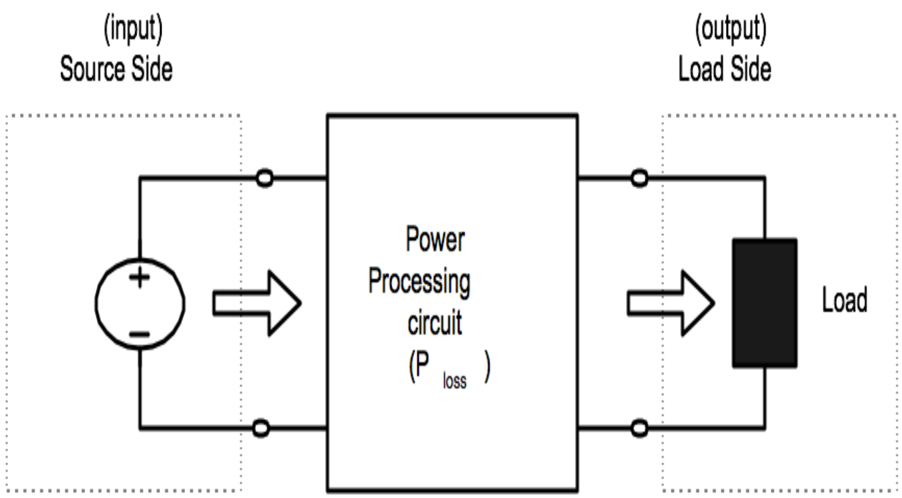


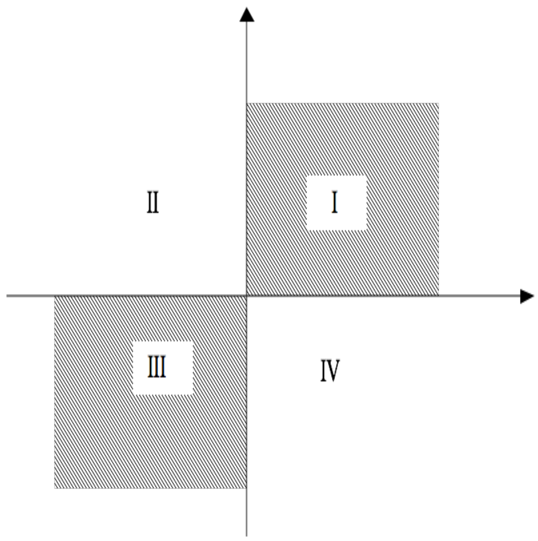
- Definition of Power Electronics
- Industry Overview and Market Share Analysis
- Multidisciplinary Nature of the Field
- Block Diagrams of Power Electronic Systems
- The Need for Power Electronics
- Types of Power Conversion
- Need for Control
- Figures of Merit for Power Electronic Converters
- Future Trends

Typical PC Power Supply

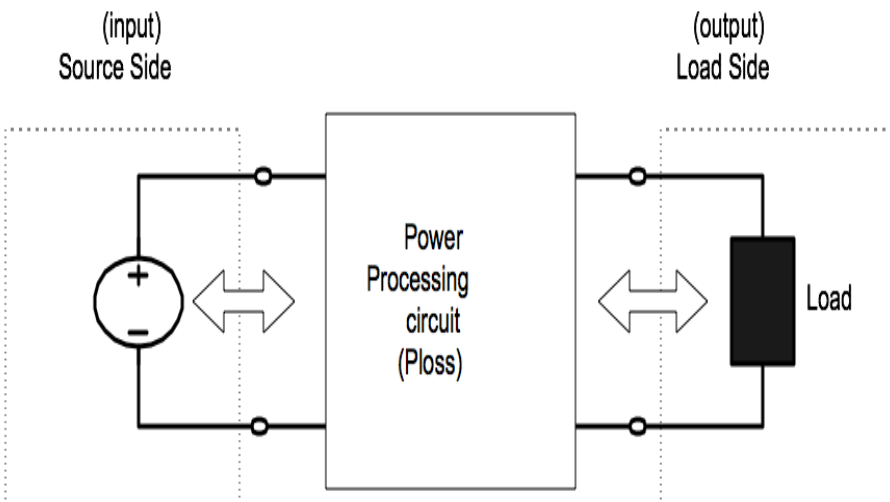


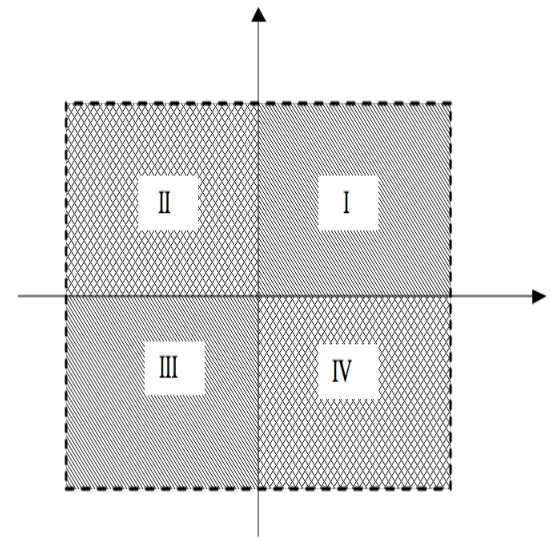
Power Flow
Unidirectional: input-to-output



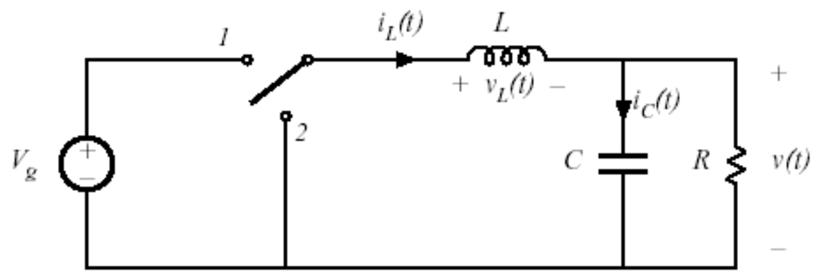


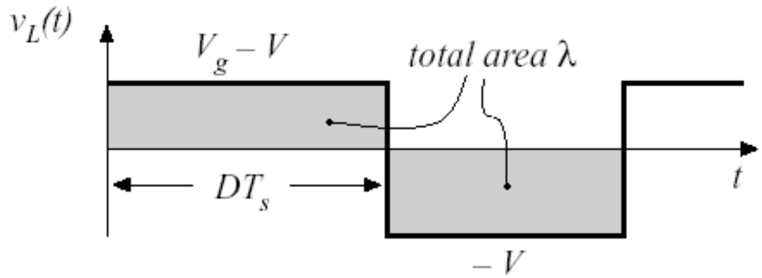
Power Flow – Bi-directional

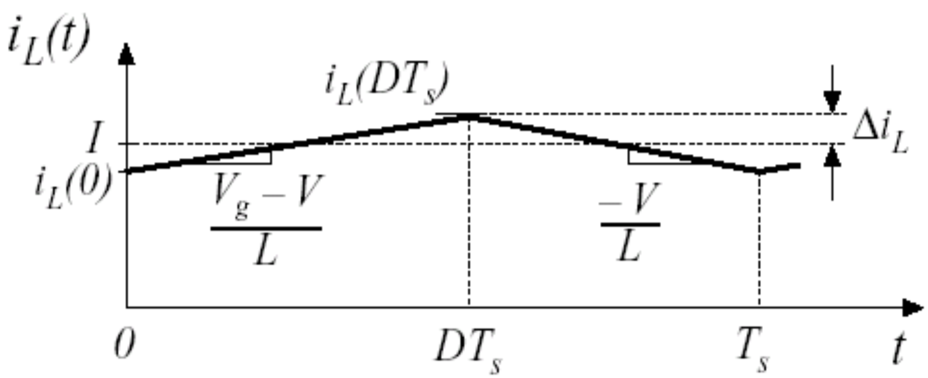




Course Content Overview: Non-isolated DC-DC Converters Continuous Conduction Mode (CCM)

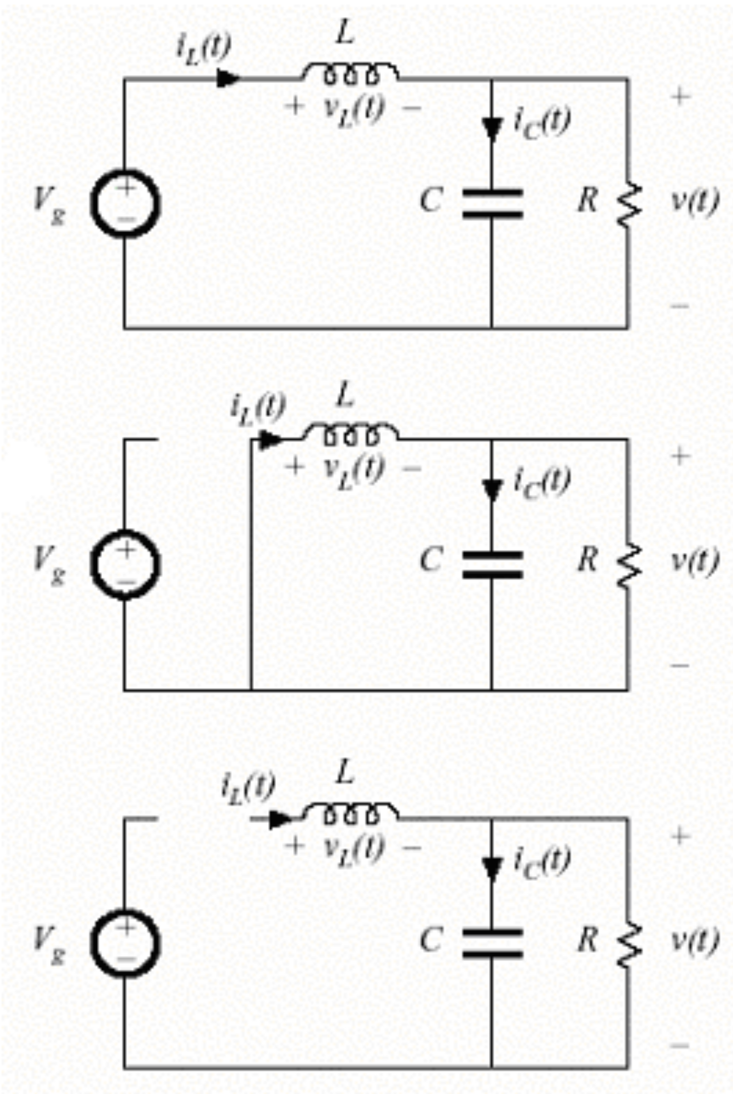






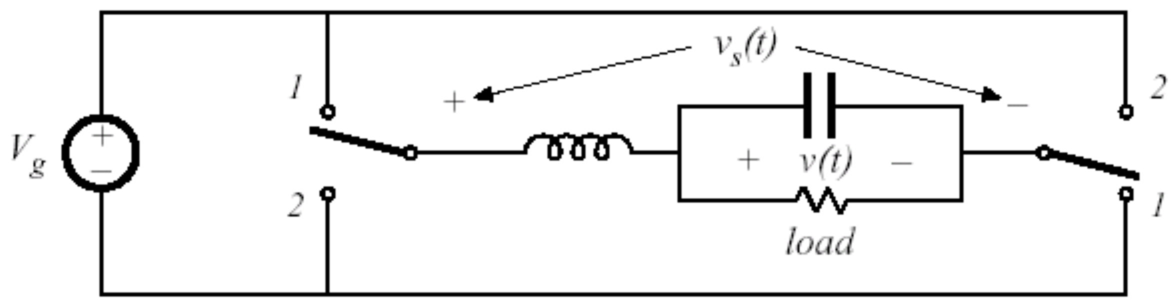
- Principles of Steady State Converter Analysis
  - Definition of Steady State
  - Inductor Volt-Second Balance
  - Capacitor Charge Balance
  - Small Ripple Approximation
  - Average Values in Steady State
  - Use of Power Conservation Principle in Converter Analysis
- Application of Analysis Techniques to Classic Converter Topologies
  - Buck, Boost, and Buck Boost
- Analysis of Fourth Order Converters

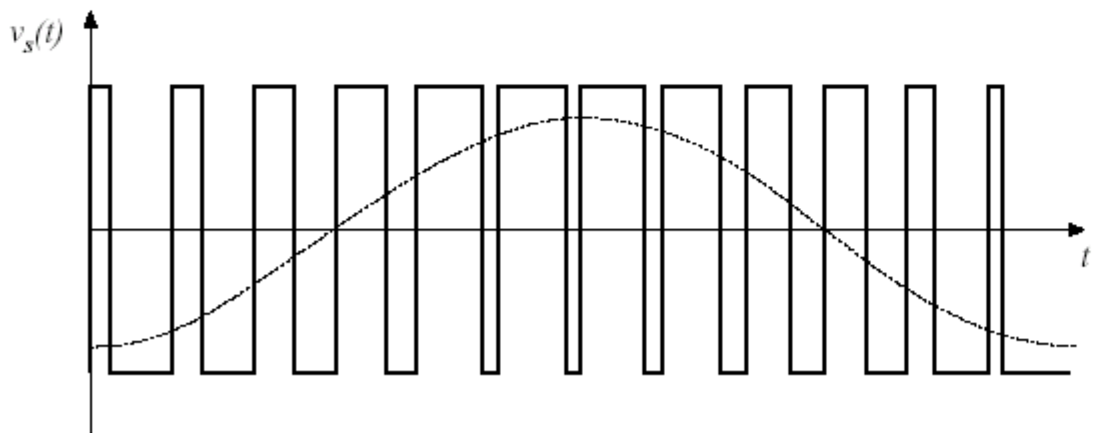
Course Content Overview:
Non-isolated DC-DC Converters
Discontinuous Conduction Mode (DCM)



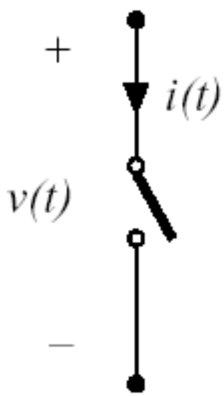
- Description of DCM
- At what operating condition does DCM occur?
- Application of Steady State Analysis Principles to Converters in DCM
  - Buck
  - Boost
  - Buck-Boost
  - Cuk
- Properties of Converters in DCM

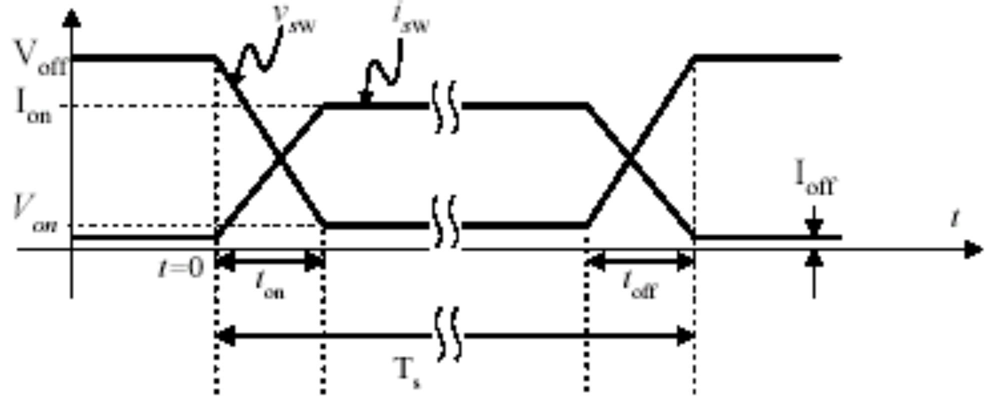
Classic Inverter Scheme

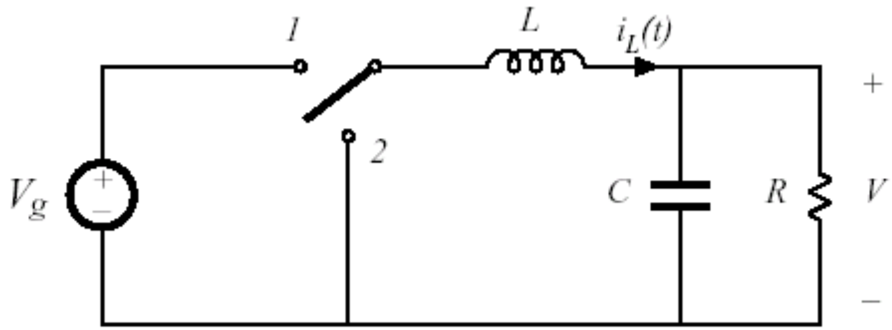




Course Content Overview: Switching Concepts

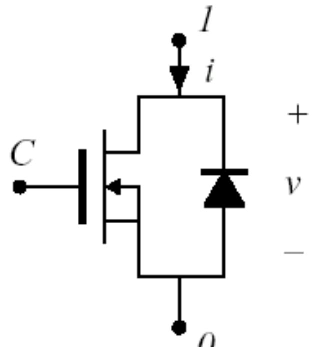


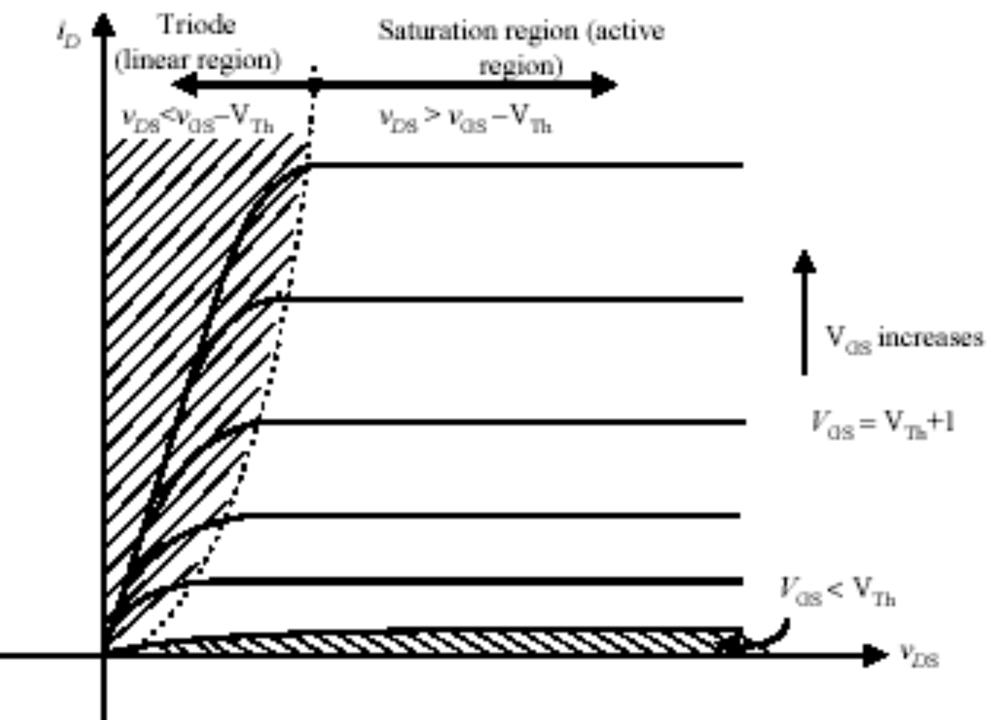




- The Need for Switching in Power Electronic Circuits
- Efficiency Example Comparing Power Supply Designs
- Ideal Switch Discussion
- Ideal Switch Types
- Practical Switch Characteristics

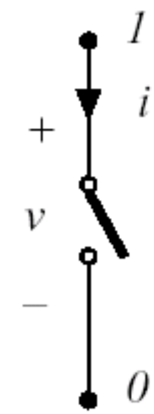
Course Content Overview: Semiconductor Device Overview





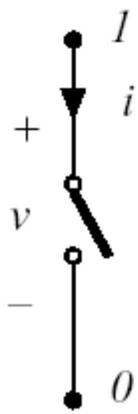
- Discussion of Available Power Semiconductor Devices
  - Power Diode
  - BJT
  - Power MOSFET
  - IGBT
  - SCR
  - GTO
  - TRIAC
- Focus on Device i-v Characteristics
- Comparison of Switching Devices
- Survey of Commercially Available Devices
- Future Trends

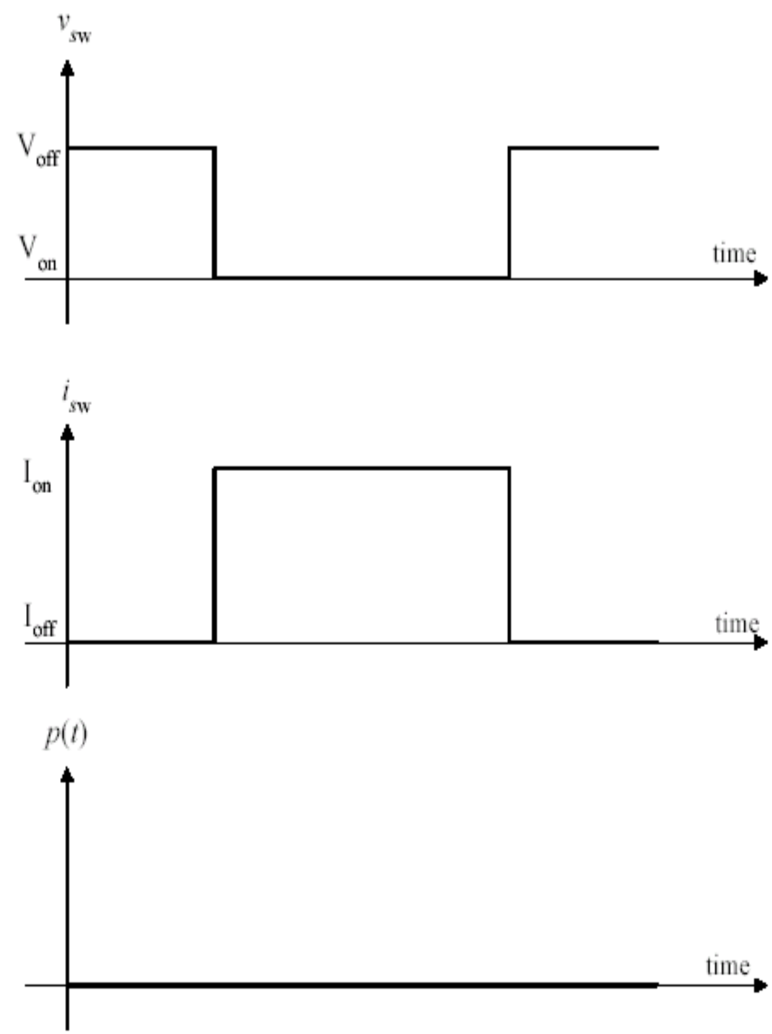
Ideal Switch Characteristics



- Zero on-state resistance
  - No forward voltage drop when on
- Infinite off-state resistance
  - No leakage current when off
- Current limitless when on-either direction
  - Conduction current a function of external components only
- No limit on amount of voltage across switch when off
  - Blocking voltage infinite (forward or reverse)
- Switch can transition from on-off or off-on instantaneously when commanded to

Ideal Switch i-v Characteristics (Transition)





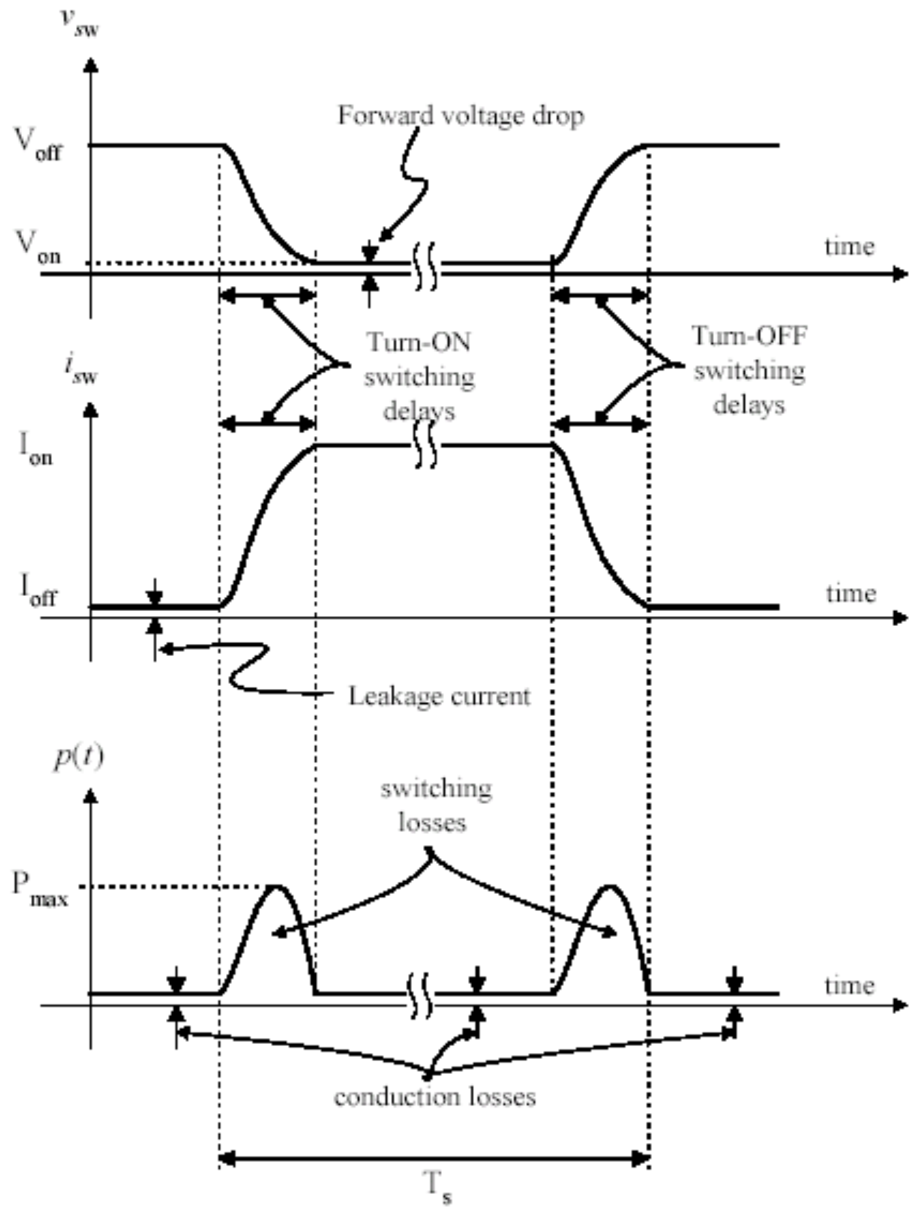
- **Previous desirable conditions mean, no power loss by any mechanism (conduction, leakage, or switching)**
  - **Switch transition-No overlap**
  - **Von=0V, Ioff=0A**

Practical Switch

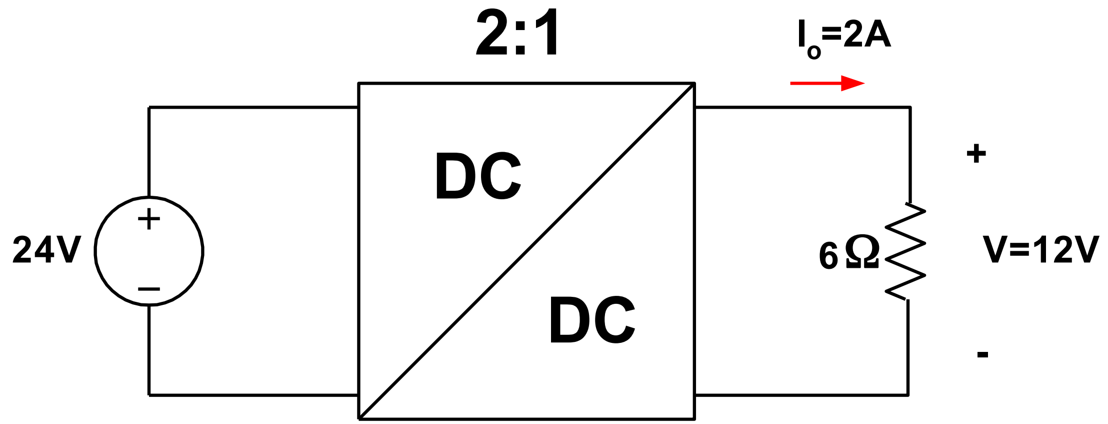
- **Although Semiconductor Industry has produced amazing devices, the "real world" switch is not ideal**
  - **Limited conduction current when the switch on, limited blocking voltage when the switch is in the off**
    - **Both are directional in practical switch**
  - **Limited switching speed that caused by the finite turn-*on* and turn-*off* times**
    - **Real world (Semiconductor) switches are charge driven**
  - **Finite, nonzero *on*-state and *off*-state resistances**
    - **There is a I^2R loss when on and some leakage when off (very small)**

Practical Switch i-v Characteristics (Transition)

- ***<u>This is root cause of the single major source of loss in PE converters</u>***
  - ***<u>Conduction- When switch is in on state (off state too, to a lesser degree)</u>***
  - ***<u>Switching Losses- When switch is transitioning from on to off or off to on</u>***

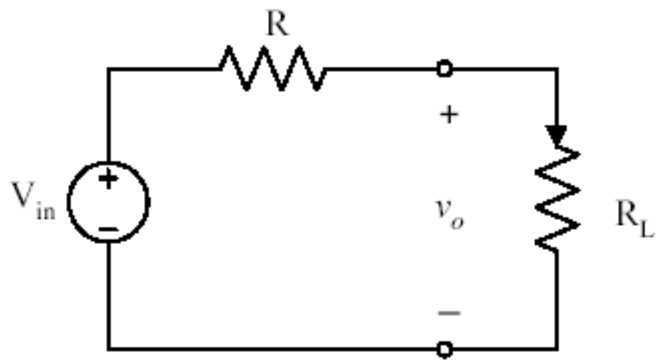


Theoretical Efficiency Example



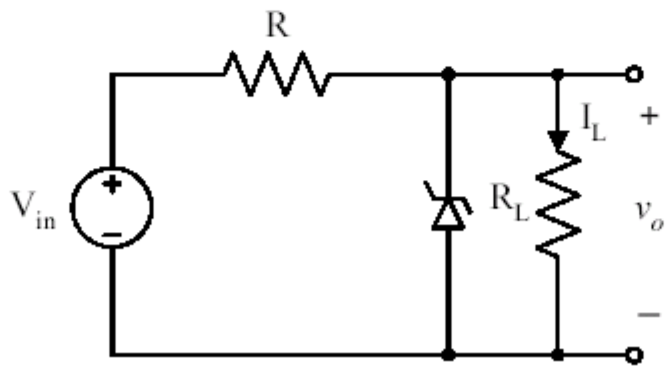
- We' ll do an example to underscore why switching is the most energy efficient choice
- Consider the design of a DC-DC converter as shown above
- Design requires 24V step down to 12V across a 6 Ohm resistive load
- Let' s investigate, some possible options

Theoretical Efficiency Example
Voltage Divider



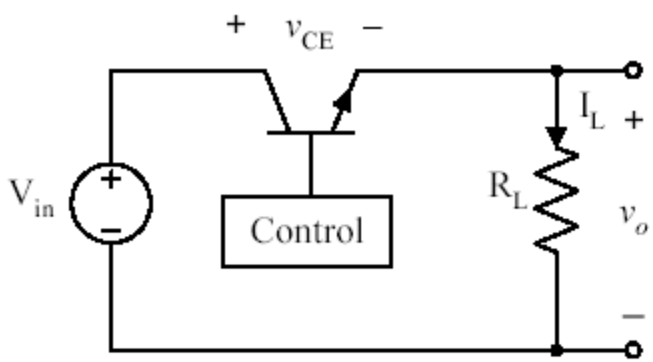
- A simple voltage divider can do job
- R must be set to 6 Ω
- Load cannot change-R fixed so no opportunity for control
- Losses are high η=50%

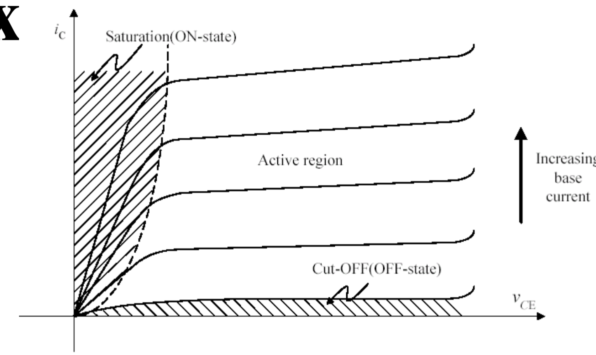
Theoretical Efficiency Example Zener Regulator



- **Need some control (regulation)**
- **A Zener Regulator will allow for load variation**
- **Assume Vz=12V, Iz@12V=.2A , Rdrop=5.5Ω**
- **Pin=Pout+Prdrop+Pzener=24W+26.2W+2.4W=52.6W**
- **η=46%**

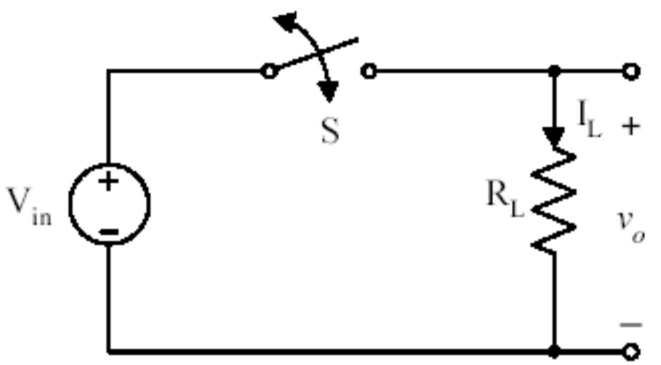
Theoretical Efficiency Ex Regulator

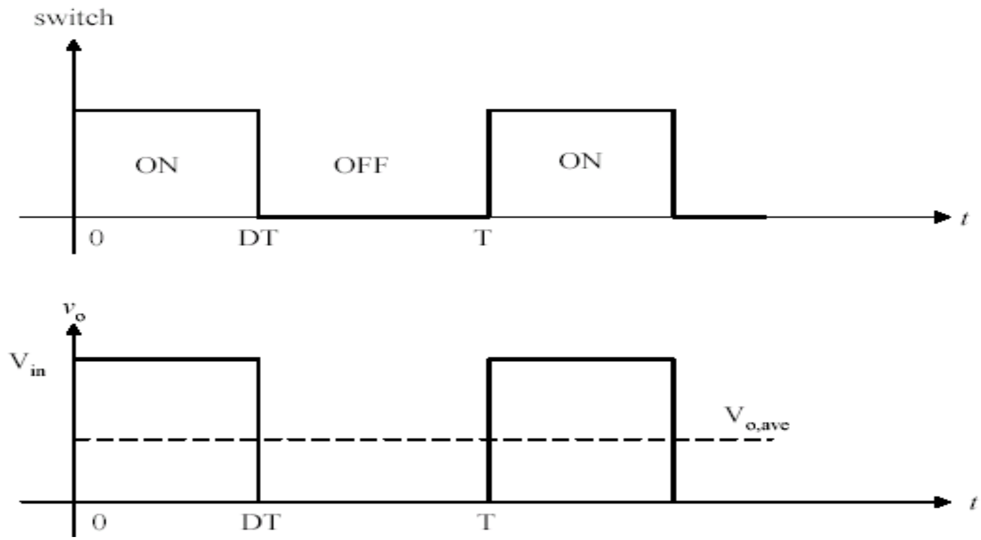




- **Drop resistor inefficient means**
- **Direct source connection is preferable**
- **Try linear regulator**
  (Similar to implementation 7805, LM317 etc.
- **Assume Vce=12V**
- **Pin=Pout+Pnpnloss=24W+24W=50W**
- **η=50%**

Theoretical Efficiency Example
Duty Ratio Controlled Switch





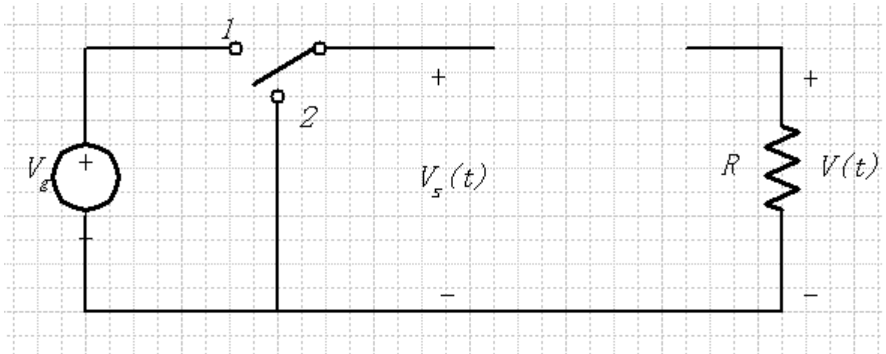
$$V_{o,ave} = \frac{1}{T}\int_0^{TD} V_{in}\, dt = V_{in} D$$

- **Instead of operating transistor in active mode try using as switch**
- **Low Pass filter required to extract DC**
- **η=100%**

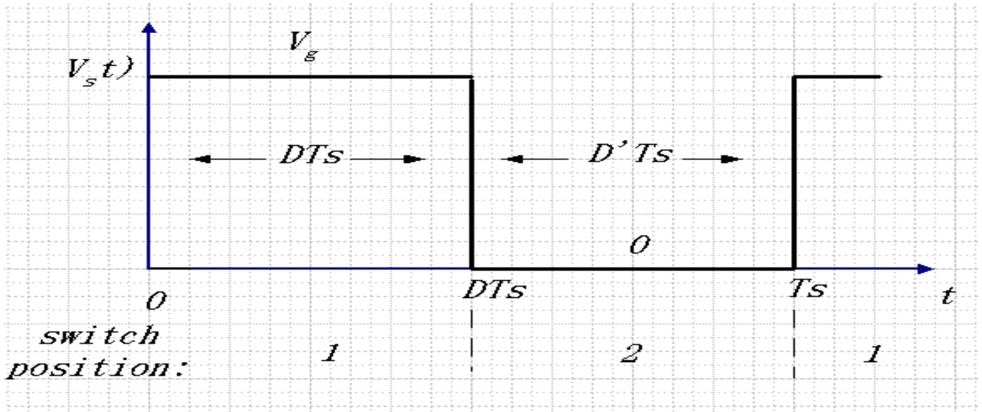
Circuit Implementation
Duty Ratio Controlled Switch-SPDT

SPDT switch changes dc component

- **Note-all power semiconductor devices act as SPST switch**



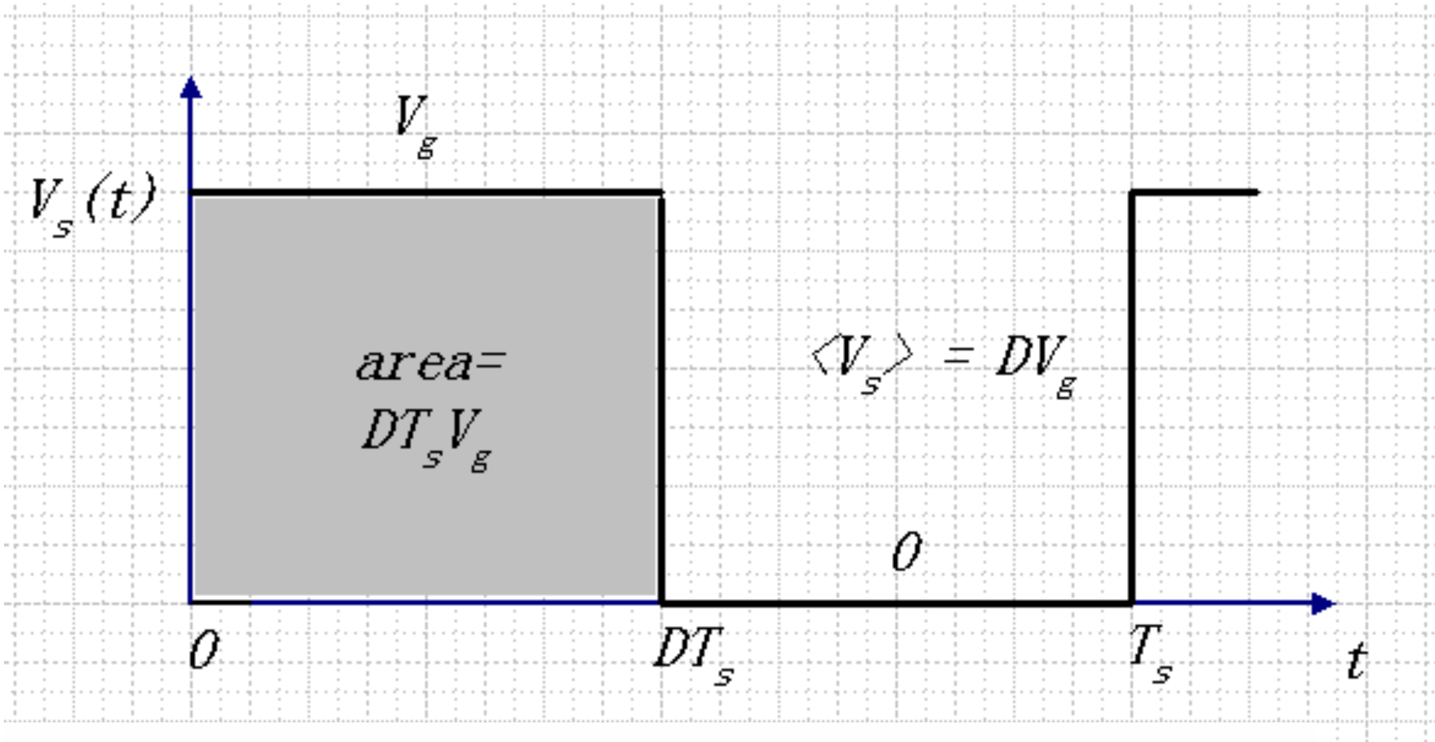
Switch output voltage waveform



Duty cycle *D*:
$0 \leq D \leq 1$

complement D':
$D' = 1 - D$

DC Component

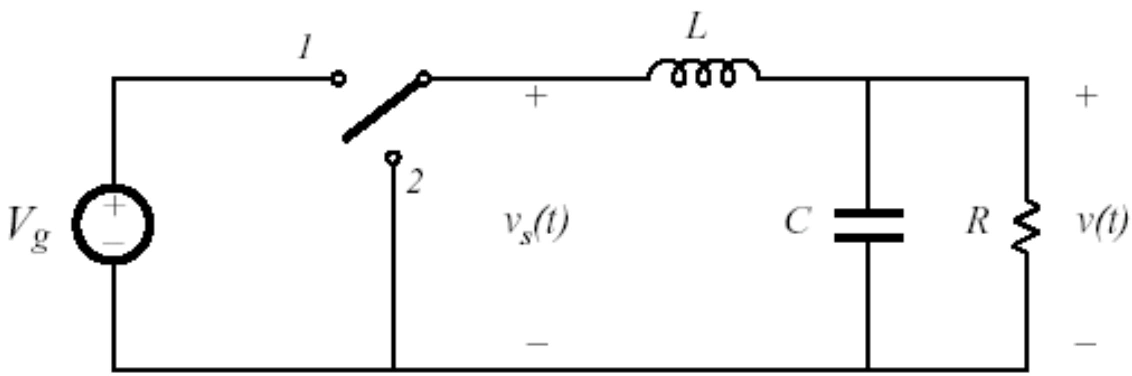


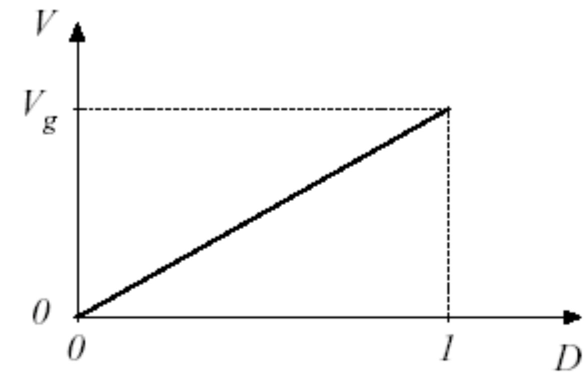
Fourier analysis: Dc component = average value

$$\langle v_s \rangle = \frac{1}{T_s}\int_0^{T_s} v_s(t)\, dt$$

$$\langle v_s \rangle = \frac{1}{T_s}(DT_sV_g) = DV_g$$

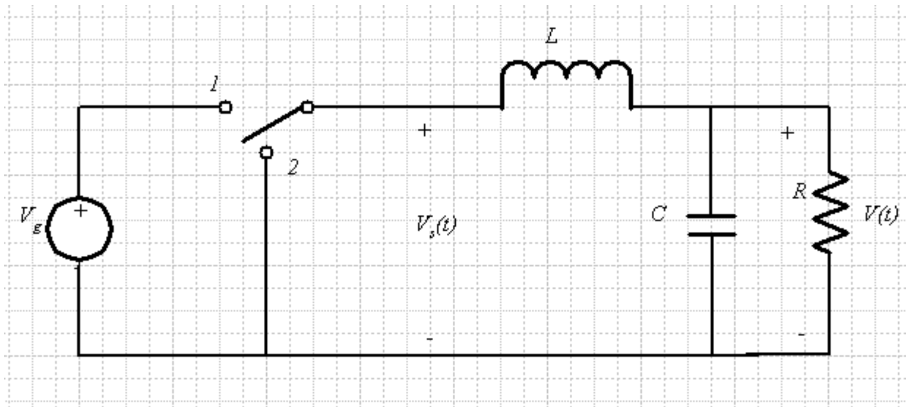
Step Down Converter-Buck

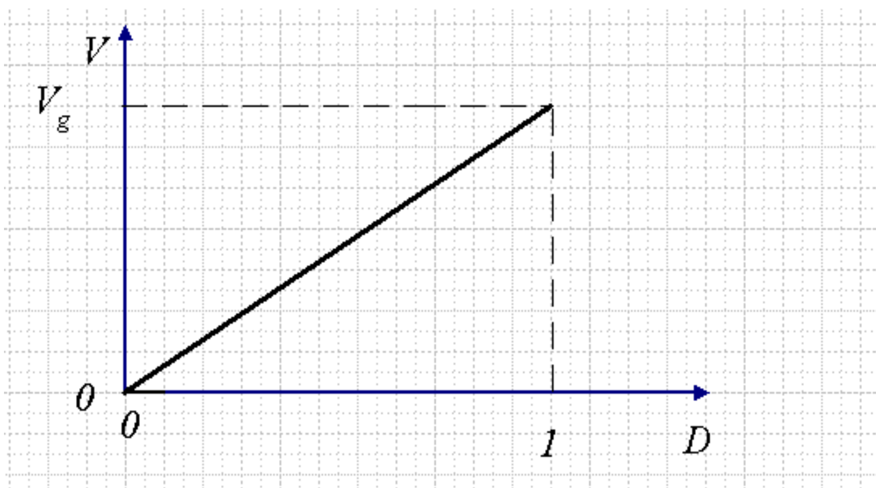




- **Low Pass extracts DC**
- **Position 2 allows for current "freewheeling"**
- **Vo can be controlled by adjusting D (Switching Period/Frequency Fixed), Vo/Vin = D**
- **Ideally, is no switch/filter loss, η=100%**
  - **We assume an ideal switch here**

Buck Converter





- **Switch Position 2 for allow for uninterrupted inductor current flow**
- **LPF for smoothing of pulse for constant DC output**
- **Capacitor hold a DC value for the load when switch in position 1 (Inductor current charge)**
- **2nd Order-1 L, 1 C**

Derivation of Classic Converter

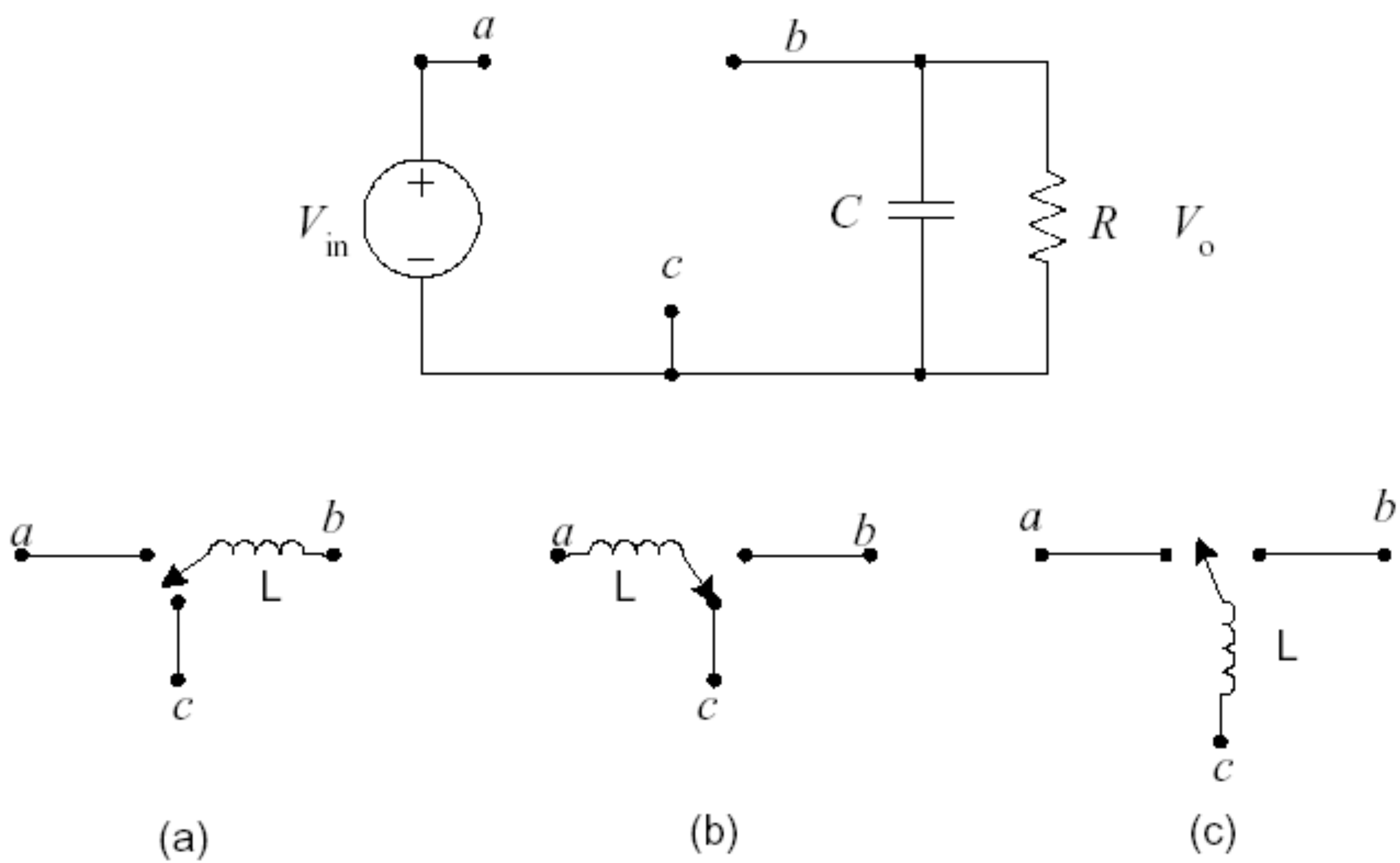
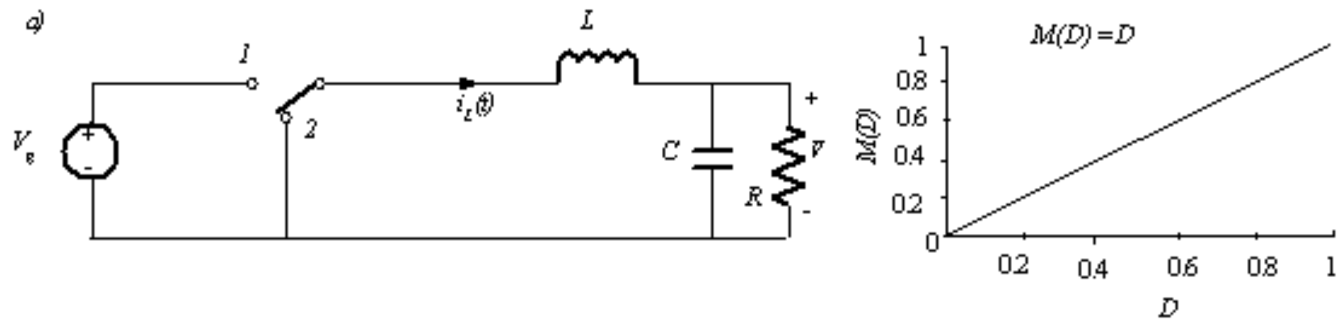


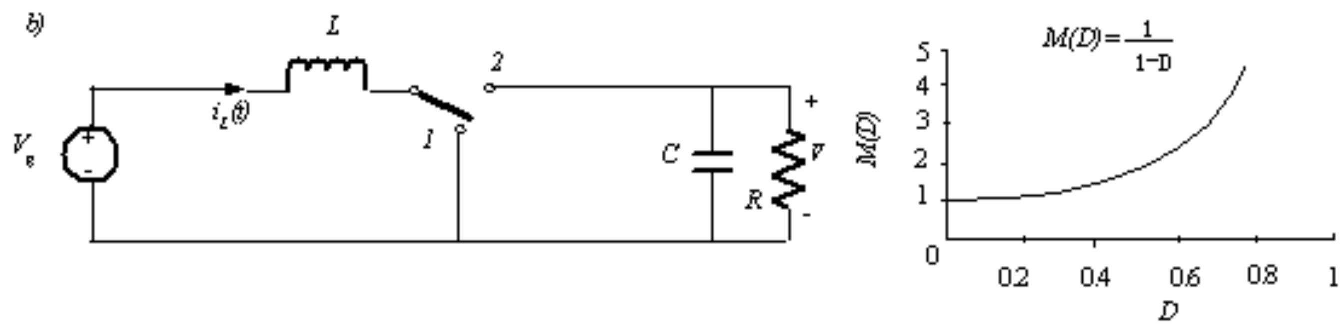
Figure 4.8: Low-pass LC filter (a) buck (b) boost (c) buck boost converter

Classic Converter Topologies

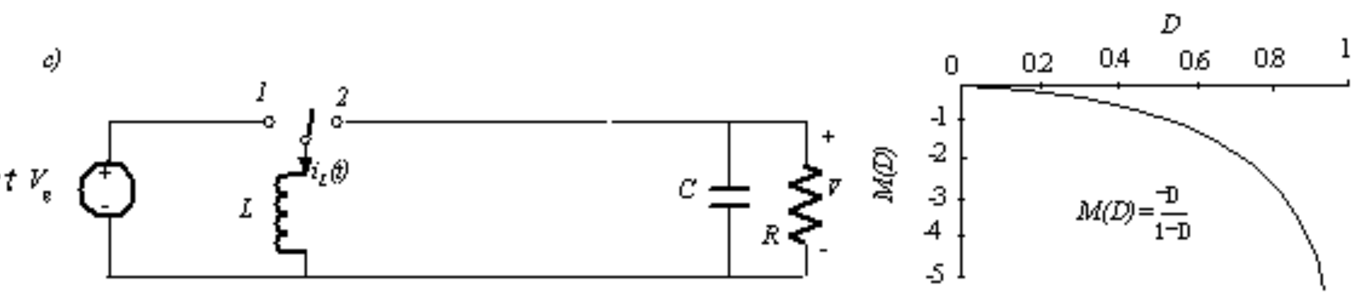
Buck



Boost



Buck–Boost



Analysis of Classic Converter Topologies

- Analysis will assume lossless components
- Exact steady state analysis would involve solution of nonlinear, 2nd Order system, we will simplify to a 1st Order System with:
  - Since RC>>Ts, output voltage nearly constant over switching period
    - Since ripple is assumed small, we assume Vo a constant during analysis (output cap not considered)
- We assume analysis of converter takes place at after it has reached steady state
  - Since steady state, average inductor voltage equals zero over switching interval (volt-sec balance)
  - Since steady state, average capacitor current over one switching interval equals zero (charge balance)

Analysis of Classic Converter Topologies

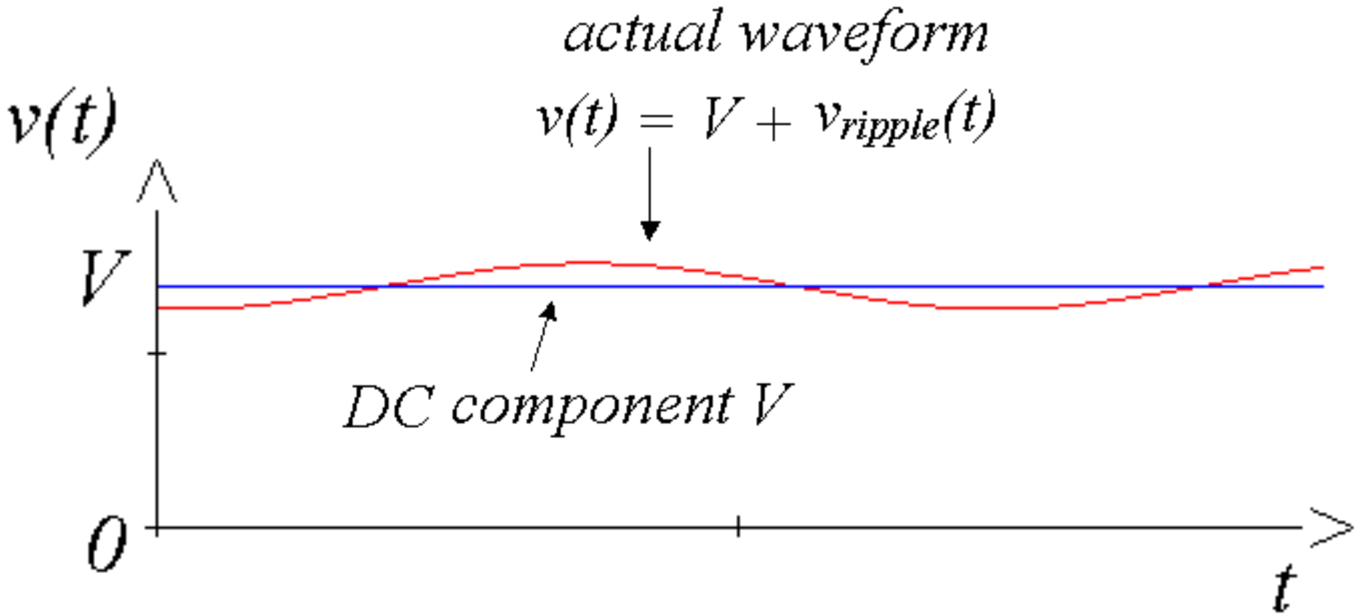
- **The preceding concepts can be expressed in terms of mathematical relations.**
- **These are tools for analysis:**
  - **$P_{out}=P_{in}$ (Power Conservation)**
  - **$i_L(t_o)=i_L(t_o+T_s)$ (Steady State)**
  - **$I_{cavg}=0$ (Charge Balance)**

$$I_c = \frac{1}{T}\int_{t_0}^{T+t_0} i_c(t)dt = 0$$

  - **$V_{Lavg}=0$ (volt-sec balance)**

$$V_L = \frac{1}{T}\int_{t_0}^{T+t_0} v_L(t)dt = 0$$

Converter Analysis Principle
Small Ripple Approximation



In a well-designed converter, the output voltage ripple is small.

Hence, the waveforms can be easily determined by ignoring the ripple:

$$\left| v_{ripple} \right| << V$$

$$v(t) \approx V$$

Converter Analysis Principle
Inductor Volt-Second Balance

Inductor defining relation :

$$v_L(t) = L\frac{di_L(t)}{dt}$$

Integrate over one complete switching period :

$$i_L(T_s) - i_L(0) = \frac{1}{L}\int_0^{T_s} v_L(t)dt$$

In periodic steady state, the net change in inductor current is zero :

$$0 = \int_0^{T_s} v_L(t)dt$$

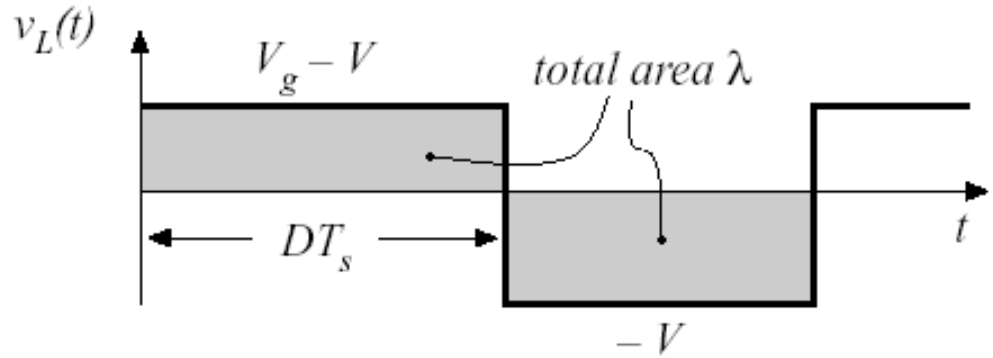
Hence, the total area (or volt-seconds) under the inductor voltage waveform is zero whenever the converter operates in steady state.
An equivalent form:

$$0 = \frac{1}{T}\int_0^{T_s} v_L(t)dt = < v_L >$$

The average inductor voltage is zero in steady state

Converter Analysis Principle Volt-Second Balance gives Voltage Gain, M

Inductor voltage waveform, previously derived:



Integral of voltage waveform is area of rectangles:

$$\lambda = \int_0^{T_s} v_L(t)\,dt = (V_g - V)(DT_s) + (-V)(D'T_s)$$

Average voltage is

$$\langle v_L \rangle = \frac{\lambda}{T_s} = D(V_g - V) + D'(-V)$$

Equate to zero and solve for *V:*

$$0 = DV_g - (D + D')V = DV_g - V \qquad \Rightarrow \qquad V = DV_g$$

Example is for Buck

Converter Analysis Principle
Capacitor Charge Balance

Capacitor defining relation:

$$i_C(t) = C\frac{dv_C(t)}{dt}$$

Integrate over one complete switching period

$$v_C(T_S) - v_C(0) = \frac{1}{C}\int_0^{T_s} i_C(t)dt$$

In periodic steady state, the net change in capacitor voltage is zero:

$$0 = \frac{1}{T}\int_0^{T_s} i_C(t)dt = < i_C >$$

Hence, the area (or charge) under the capacitor current waveform is zero whenever the converter operates in steady state. The average capacitor current is then zero.

Assignment for Thursday, Jan 15, 2015

1) Do the Academic Assignment on line

2) Review Chapter 3 and 4 and workout the details analysis of all the isolated DC-DC Converters operating in CCM and DCM modes. Send me an email to confirm your understanding of the Chs 4 and 4.