What we have studied so far

With Prof Lianping Hou

- Electric Circuits
- Power Switches
- Uncontrolled and Controllable Switches
- Heatsinks

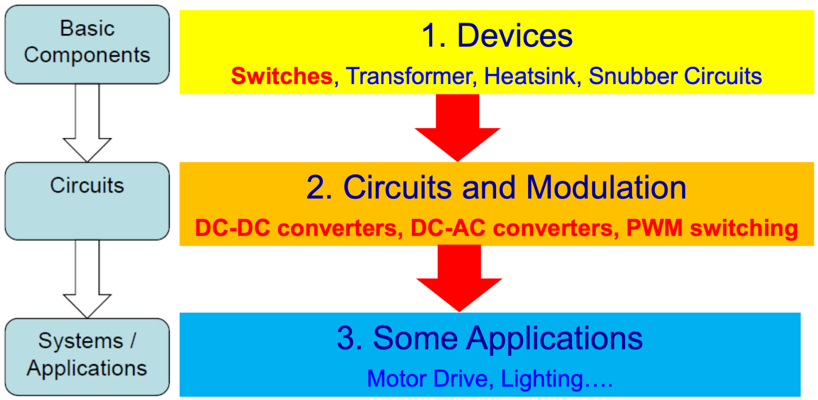
Since Week-8

- Snubber Circuits
- Switched Mode Power Supplies (DC converters)
- DC-AC converters (Inverters)
- PWM Inverters

To do

- Applications and Systems
- Revision of Numerical Questions

Course Structure



Today's Lecture

- Applications and Systems
- Numerical Problems

Power Electronics

Applications and Systems

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Reading material in Chapters 12,13,14,16,17 and 18 in the textbook

Applications - High level

- Application we have covered so far
  - Power Supplies
  - Inverters

- Other Applications
  - Motor drive applications (Chapters 12,13 and 14)
  - Electric Vehicles
  - Residential applications
  - Industrial applications
  - Electric Utility applications

Motor drive applications

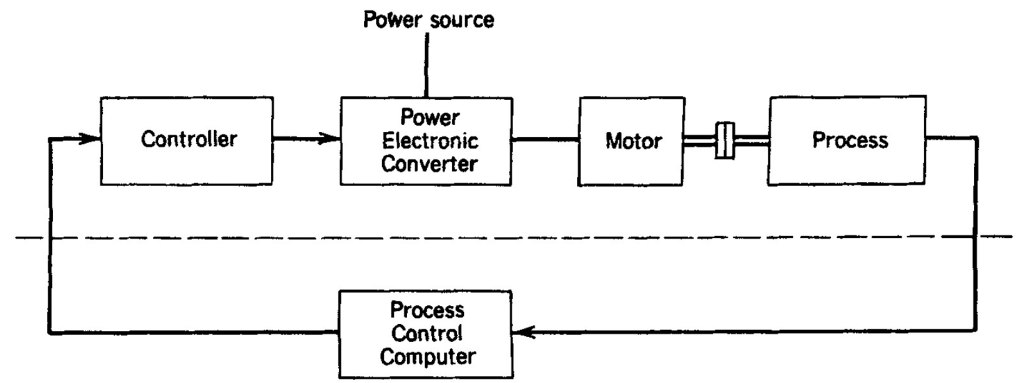


Figure 12-1 Control of motor drives.

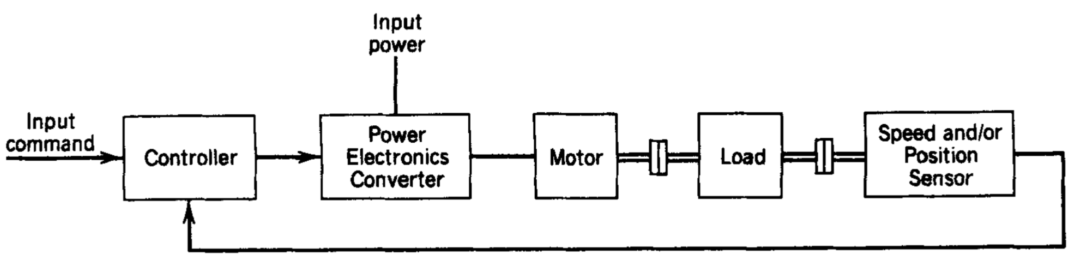
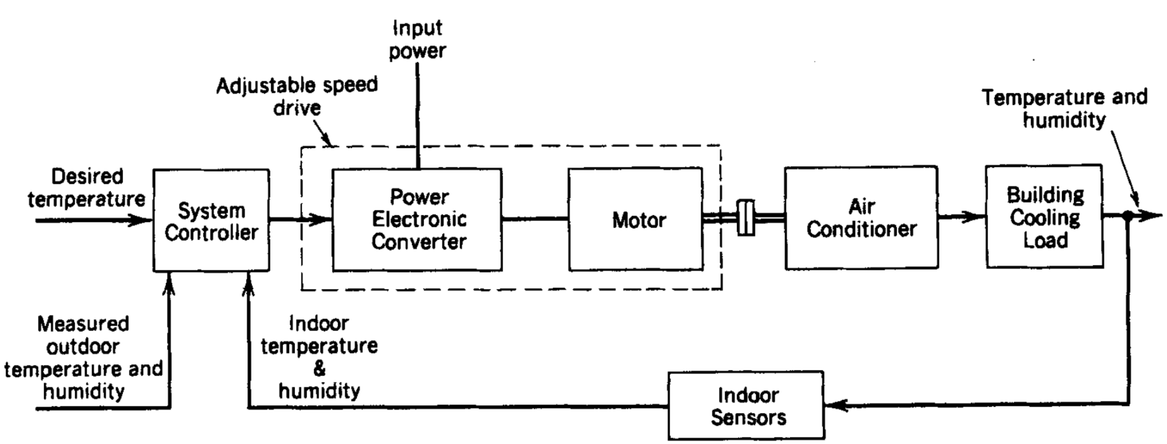
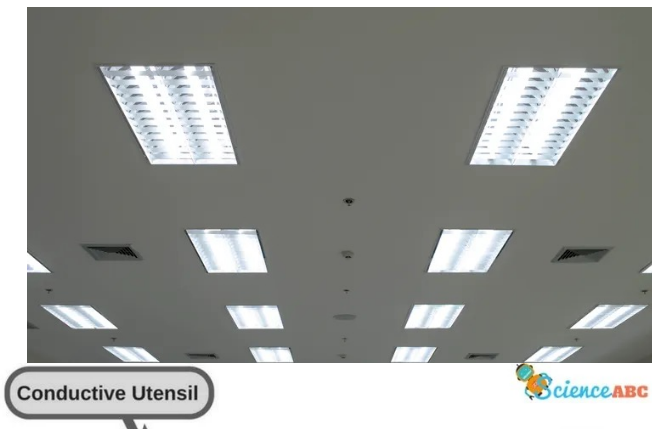


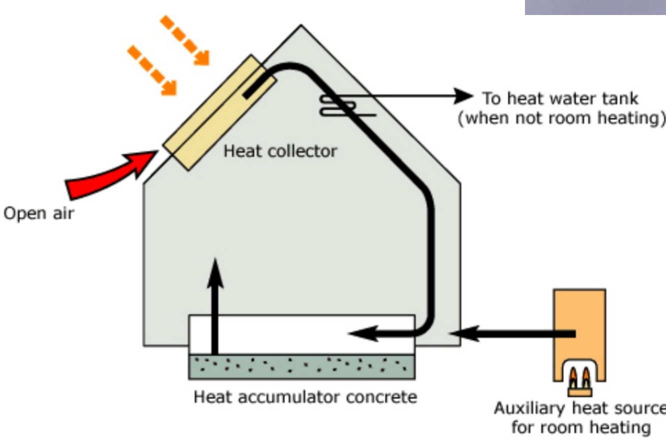
Figure 12-2 Servo drives.

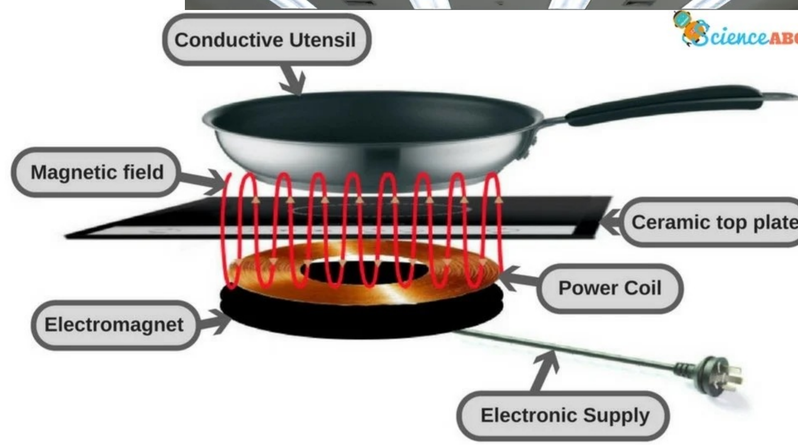


Residential Applications

- Space Heating and Air Conditioning
- High Frequency Fluorescent Lighting
- Induction Cooking



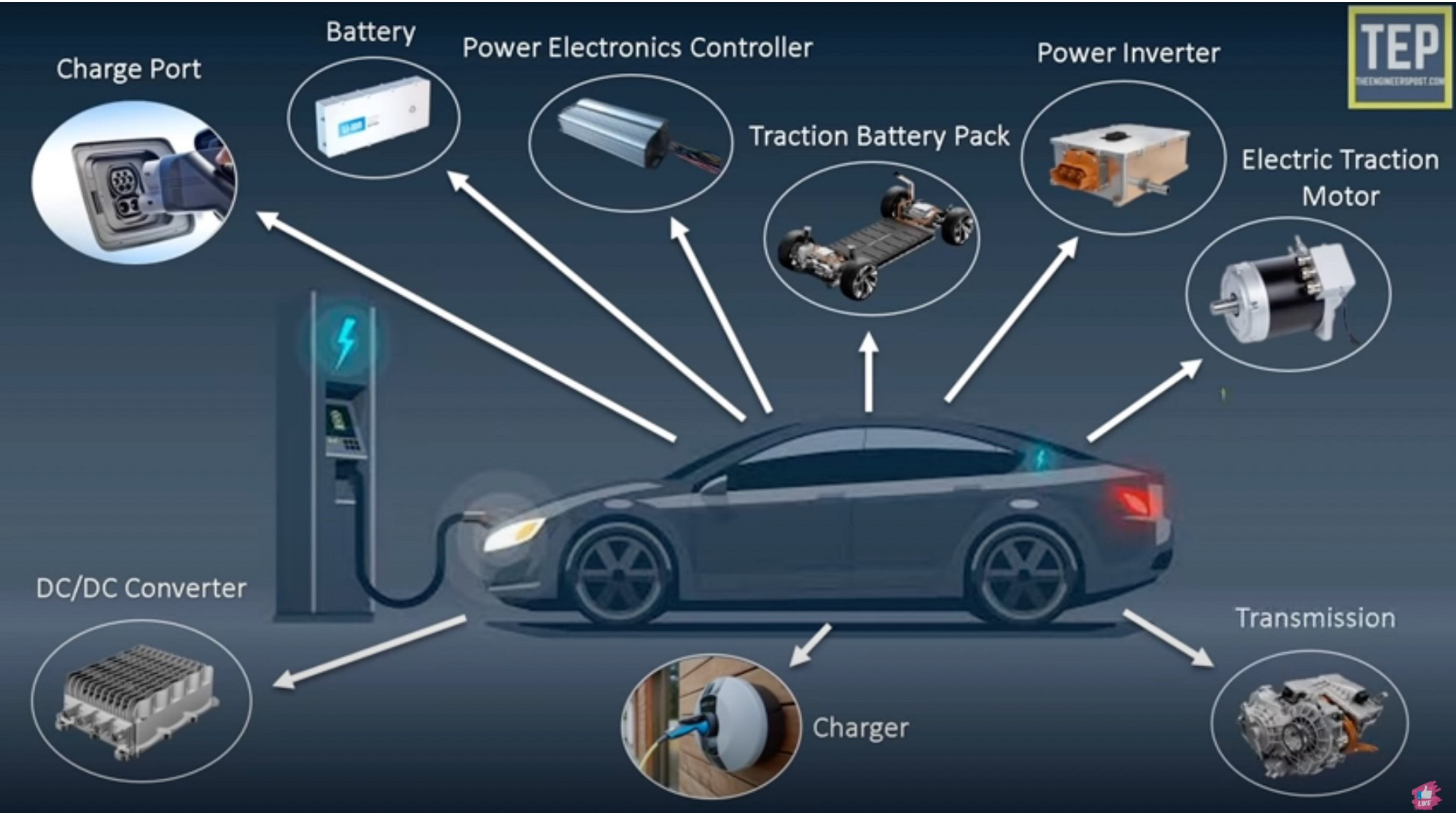


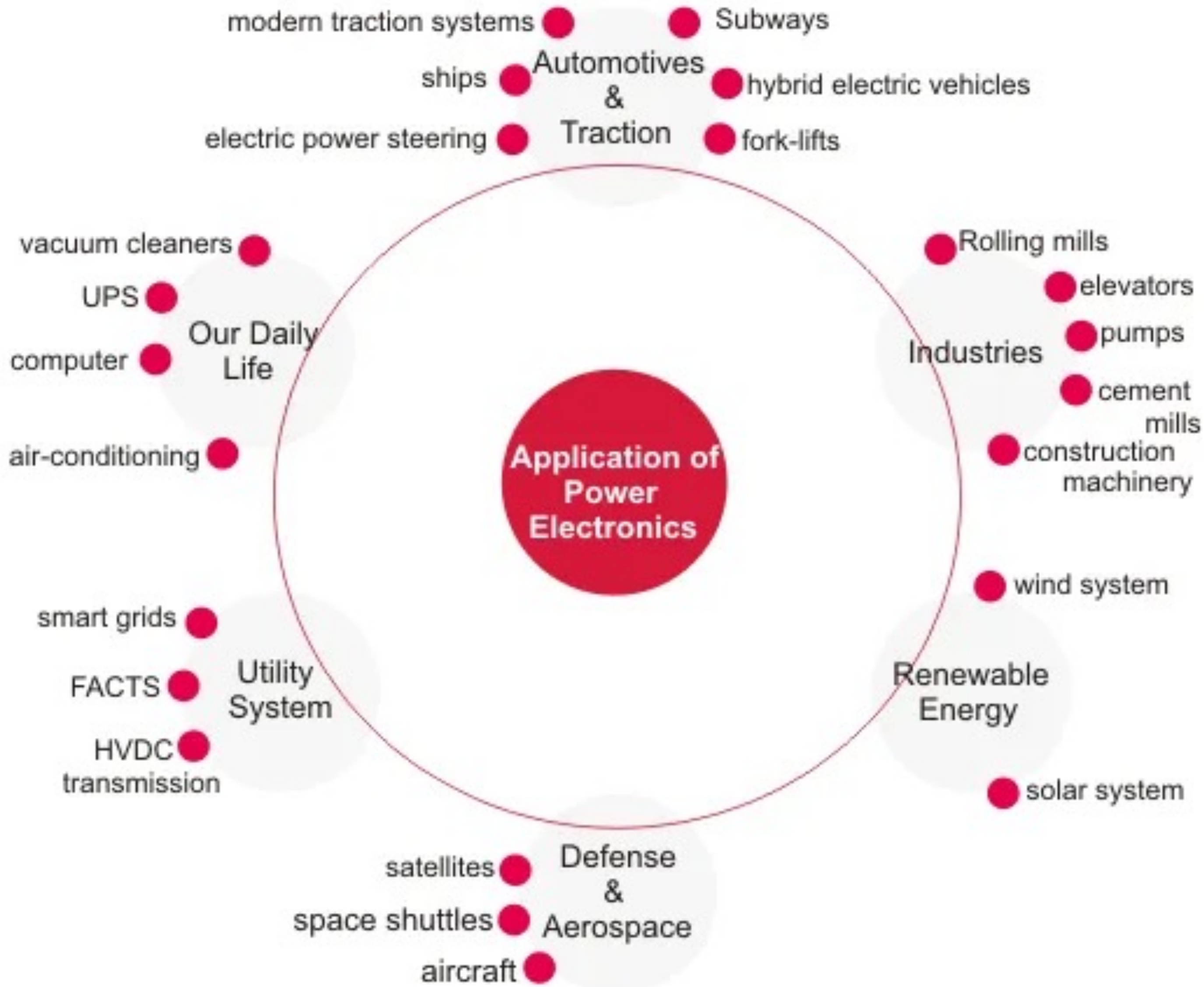


Industrial Applications

- Induction heating
- Electric welding
- Controllers

Electric Vehicle




Application of Power Electronics
Automotives & Traction
modern traction systems
Subways
ships
hybrid electric vehicles
electric power steering
fork-lifts
Industries
Rolling mills
elevators
pumps
cement mills
construction machinery
Renewable Energy
wind system
solar system
Defense & Aerospace
satellites
space shuttles
aircraft
Utility System
smart grids
FACTS
HVDC transmission
Our Daily Life
vacuum cleaners
UPS
computer
air-conditioning

Additional links for self study

- Electric Vehicle – parts and functions
  - https://www.youtube.com/watch?v=tJfERzrG-D8
- Applications
  - https://www.youtube.com/watch?v=6KHJ5JA4BbY
- https://www.electrical4u.com/application-of-power-electronics/

27-1 Consider the step-down converter circuit shown in Fig. 24-3 without the turn-on snubber. The dc input voltage V_d is 500 V, the load current $I_o = 500$ A, and the switching frequency is 1 kHz. The free-wheeling diode has a reverse-recovery time $t_{rr} = 10$ μs. The GTO has a current fall time $t_{fi} = 1$ μs, a maximum reapplied voltage rate $dv/dt = 50$ V/μs, and a maximum controllable anode current $I_{AM} = 1000$ A.

(a) Find the appropriate values for resistance R_s and capacitance C_s for the turn-off snubber circuit.

(b) Estimate the power dissipated in the snubber resistance.

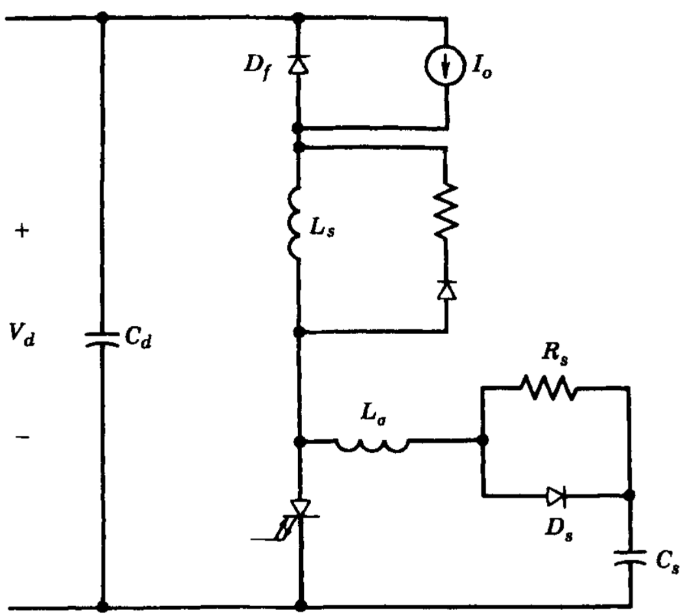


Figure 24-3 Step-down converter circuit using a GTO as the switching device with turn-on and turn-off snubbers.

27.1

$V_d = 500V$

$I_o = 500A$

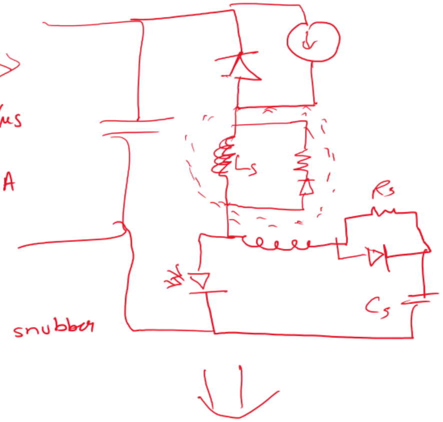
$f_s = 1kHz$

$t_{rr} = 10\mu s$

$t_{fi} = 1\mu s$

$\frac{dv}{dt} = 50V/\mu s$

$I_{AM} = 1000A$



a) $R_s = ?$, $C_s = ?$; turn-off snubber

$$\boxed{\frac{dv}{dt} = \frac{I_o}{C_s}} \Rightarrow C_s = I_o\left(\frac{dv}{dt}\right)^{-1}$$

$$C_s = (500)\left(\frac{1}{50\times10^6}\right) = \frac{500}{5}\times10^{-7}$$

$$C_s = 100\times10^{-7} = 10\times10^{-6} = 10\mu F$$

$$I_{Cs_{max}} = I_{AM} - I_o - I_{rr}$$

Assuming $I_{rr} = 0.2 I_o$

$$I_{Cs_{max}} = 1000 - 500 - (0.2)(500)$$

$$I_{Cs_{max}} = 400A$$

$$R_s = \frac{V}{I_{Cs_{max}}} = \frac{500}{400} = 1.3\Omega$$

b) Power dissipated $= fCV^2$

$$= (1\times10^3)(10^{-5})(500)^2$$

$$= 10^{-2}(250000)$$

$$= 2.5kW$$

27-2 The GTO in the circuit of Problem 27-1 is to be protected by a turn-on snubber circuit such as is shown in Fig. 24-3. The maximum rate of rise of the anode current, di_A/dt, is 300 A/μs. Find appropriate values for the inductance and resistance.

27.2

$$\frac{di_A}{dt} = 300\ A/\mu s$$

$L_s = ?$; $R_s = ?$

$$V = L\frac{di_A}{dt} \Rightarrow 500 = L(300 \times 10^{6})$$

$$L = \frac{500}{300} \times 10^{-6} = 1.7 \times 10^{-6} = 1.7\mu H$$

Voltage across GTO at turn-off $= V_d + I_o R_s$

$$I_o R_s = 0.2 V_d$$

$$R_s = \frac{(0.2)(500)}{500} = 0.2\,\Omega$$

27-4 Consider the flyback converter circuit shown in Fig. 27-6. The input voltage is 100 V as is the dc output voltage. The transformer has a 1:1 turns ratio and a leakage inductance of 10 μH. The transistor, which can be considered as an ideal switch, is driven by a square wave with a 50% duty cycle. The snubber resistance is zero. The diode has a reverse-recovery time t_{rr} of 0.3 μs.

(a) Draw an equivalent circuit suitable for snubber design calculations.

(b) Find the value of snubber capacitance C_s that will limit the peak overvoltage to 2.5 times the dc output voltage.

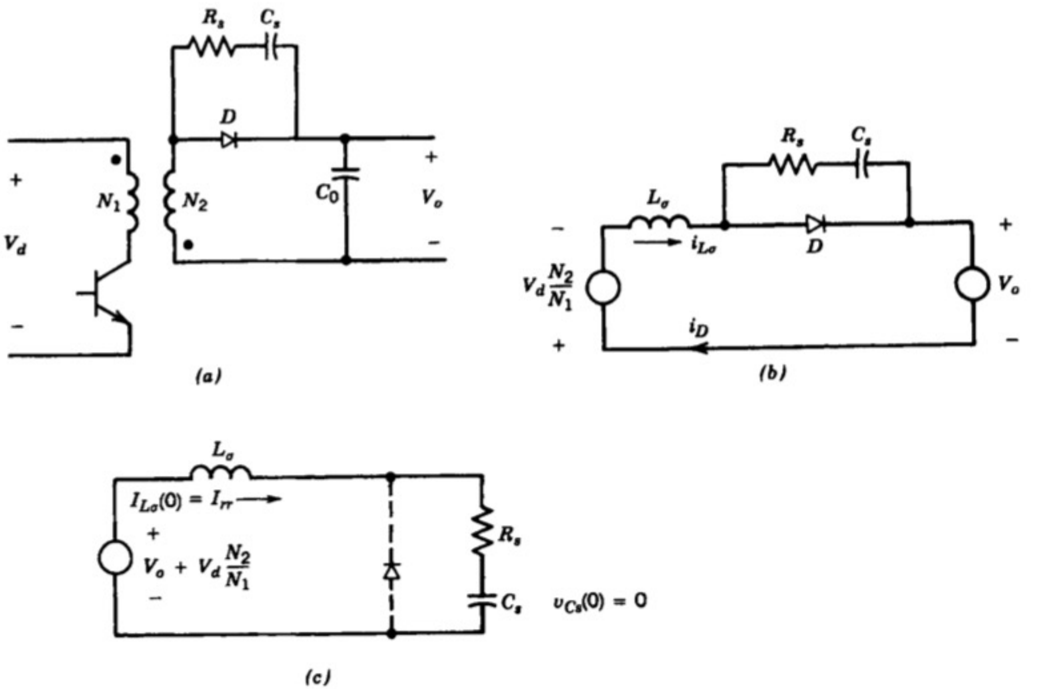


Figure 27-6 (a) Flyback converter circuit operating in an incomplete demagnetization mode. (b) Equivalent circuit on the secondary side and (c) the simplified equivalent circuit after the snap-off of the diode current. L_σ is the transformer leakage inductance.

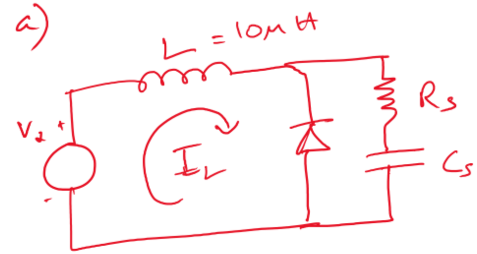
27-4

$V_d = 100V$, $V_o = 100V$, $V_{IN} = 200V$

$L = 10 \mu H$

$t_{rr} = 0.3 \mu s$

a)



$V = L \frac{di}{dt} = (100) + (100) = 200V$

$\frac{di}{dt} = \frac{200}{10 \times 10^{-6}} = 20 \times 10^{6}\ A/s$

$\frac{di}{dt} = \frac{I_L}{t_{rr}} \Rightarrow I_L = (20 \times 10^{6})(0.3 \times 10^{-6})$

$I_L = 6A$

b) $C_s = ?$

$V_{Cs,max} = 2.5 \times 200 = 500V$

$V = IR$
$\Rightarrow R = \frac{V}{I}$

$R_s = \sqrt{\frac{L}{C_{switch}}} \Rightarrow R_s^2 = \frac{L}{C_{switch}}$

$C_{switch} = \frac{L}{R_s^2} = L\frac{I^2}{V^2} = \frac{(10\times10^{-6})(6)^2}{(200)^2}$

$C_{switch} = 9nF$

$V_{Cs,max} = V_{IN}\left(1 + \sqrt{1 + \frac{C_{switch}}{C_s}}\right)$

$V_{Cs,max} = 200\left(1 + \sqrt{1 + \frac{C_{switch}}{C_s}}\right) = 500V$

$1 + \sqrt{1 + \frac{C_{switch}}{C_s}} = \frac{500}{200}$

$\sqrt{1 + \frac{C_{switch}}{C_s}} = \frac{5}{2} - 1$

$+\frac{C_{switch}}{C_s} = (1.5)^2 \Rightarrow \frac{C_{switch}}{C_s} = 2.25 - 1$

$\frac{C_{switch}}{C_s} = 1.25$

$C_s = \frac{9}{1.25} = 7.2nF$

27-5 Repeat Problem 27-4 with a resistance R_s included in the snubber circuit. Find both the value of snubber capacitance and optimum value of snubber resistance.

27.5

$$R_{snubber} = \sqrt{\frac{L}{C_{snubber}}} = \sqrt{\frac{10\times10^{-6}}{9\times10^{-9}}}$$

$$\boxed{R_s = 33.3\,\Omega}$$

27-6 Estimate the power dissipated in the snubber resistance found in Problem 27-4 if the square-wave switching frequency is 20 kHz.

27.6

$$P = fCV^2$$

$$P = (20\times10^3)(7.2\times10^{-9})(200)^2$$

$$P = 5.76\ W.$$

7-1 In a step-down converter, consider all components to be ideal. Let $v_o \simeq V_o$ be held constant at 5 V by controlling the switch duty ratio D. Calculate the minimum inductance L required to keep the converter operation in a continuous-conduction mode under all conditions if V_d is 10–40 V, $P_o \geq$ 5 W, and f_s = 50 kHz.

7-1

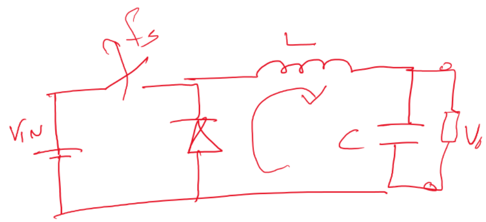
$V_o = V_o = 5V$

$L = ?$

$10 < V_d < 40V$

$P_o \geqslant 5W$

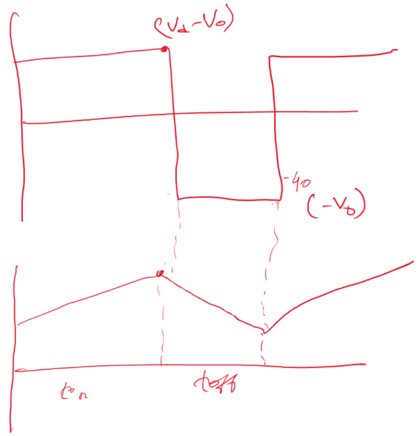
$f_s = 50kHz$



$$\boxed{I_o = \frac{DT_s}{2L}(V_d - V_o)}$$

$P_o = I_o V_o$

$I_o = \frac{5}{5} = 1A$



$L = \frac{DT_s}{2I_o}(V_d - V_o) \Rightarrow L = \frac{0.125}{2(50\times10^3)(1)}(40-5)$

$\hookrightarrow L = 4.375\times10^{-5} = 43.75\mu F$

$D = \frac{5}{40} = 0.125$

7-2 Consider all components to be ideal. Assume $V_o = 5$ V, $f_s = 20$ kHz, $L = 1$ mH, and $C = 470$ µF. Calculate ΔV_o (peak–peak) if $V_d = 12.6$ V, and $I_o = 200$ mA.

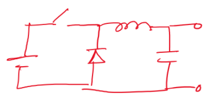
7-2

$V_o = 5V$ $\qquad$ $V_d = 12.6V$

$f_s = 20kHz$ $\qquad$ $I_o = 200mA$

$L = 1mH$ $\qquad$ $\Delta V_o = ?$

$C = 470\mu F$



$$\Delta V_o = \frac{\Delta Q}{C} = \frac{1}{C} \cdot \frac{1}{2} \cdot \frac{\Delta i_L}{2} \cdot \frac{T_s}{2}$$

$$\Delta i_L = \frac{V_o}{L}(1-D)T_s$$

$$\Delta V_o = \frac{1}{8} \frac{T_s^2(1-D)}{LC}$$

$$D = \frac{V_o}{V_{in}} = \frac{5V}{12.6V} = 0.397$$

$$\Delta V_o = \frac{1}{8} \cdot \frac{(1-0.397)}{(470\times10^{-6})(1\times10^{-3})(20000)^2}$$

$$\Delta V_o = 2.01mV$$

7-7 In a step-up converter, consider all components to be ideal. Let V_d be 8–16 V, $V_o = 24$ V (regulated), $f_s = 20$ kHz, and $C = 470\ \mu$F. Calculate L_{min} that will keep the converter operating in a continuous-conduction mode if $P_o \geq 5$ W.

7-7 Step-up (boost)

$8 \leq V_d \leq 16$

$P_o \geq 5W$

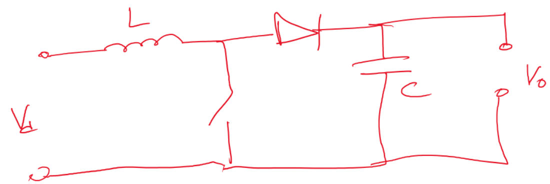
$L_{min} = ?$

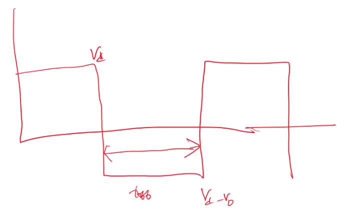
$V_o = 24V$

$f_s = 20kHz$

$C = 470\mu F$

$I_o = \frac{P}{V} = \frac{5}{24} = 0.2083A$





$V = L\frac{di}{dt}$

$L = V\frac{\Delta t}{\Delta i}$

$\boxed{D = 1 - \frac{V_d}{V_o}}$

$\boxed{I_o = \frac{T_s V_o}{2L} D(1-D)^2}$

$\frac{T_s}{t_{off}} = \frac{1}{1-D}$

$1 - D = \frac{t_{off}}{T_s}$

$D = 1 - \frac{t_{off}}{T_s}$

for $V_d = 8V \Rightarrow D = 1 - \frac{8}{24} = 1 - \frac{1}{3} = \frac{2}{3}$

$L = \frac{T_s V_o}{2 I_o} D(1-D)^2 \Rightarrow \frac{24}{2(20000)(0.2083)} \cdot \frac{2}{3}(1-\frac{2}{3})^2$

$L = 0.213mH$

for $V_d = 16V \Rightarrow D = 1 - \frac{16}{24} = \frac{24-16}{24} = \frac{1}{3}$

$L = \frac{24}{2(20000)(0.2083)} \cdot \frac{1}{3}(1-\frac{1}{3})^2$

$L = 0.477mH$

7-8 In a step-up converter, $V_d = 12$ V, $V_o = 24$ V, $I_o = 0.5$ A, $L = 150$ μH, $C = 470$ μF, and $f_s =$ 20 kHz. Calculate ΔV_o (peak–peak).

7-8

$V_d = 12V$

$V_o = 24V$

$I_o = 0.5A$

$L = 150 \mu H$

$C = 470 \mu F$

$f_s = 20kHz$

$\Delta V_o = ?$

$$\frac{\Delta Q}{C} = \Delta V_o = \frac{V_o}{R} \cdot \frac{\phi T_s}{C} = \boxed{\frac{I_{avg} \phi T_s}{C}}$$

$$I_{avg} = \frac{I_{max} - I_o}{2}$$

$$I_{max} = \frac{V_d}{L} \phi T_s$$

$$\boxed{I_o = \frac{T_s V_o}{2L} \phi (1-\phi)^2}$$

$$\phi = 1 - \frac{V_d}{V_o} = 1 - \frac{12}{24} = 0.5$$

$$I_o = \frac{1}{2(20000)(150 \times 10^{-6})} \cdot 0.5 (1-0.5)^2$$

$$I_o = 0.5A$$

$$I_{max} = \frac{12}{(150 \times 10^{-6})} \cdot 0.5 \cdot \frac{1}{20{,}000} = 2A$$

$$I_{avg} = \frac{2 - 0.5}{2} = 0.75A$$

$$\Delta V = \frac{(0.75)(0.5)}{(20{,}000)(470 \times 10^{-6})} = 39mV$$

7-12 In a buck–boost converter, consider all components to be ideal. Let V_d be 8–40 V, $V_o = 15$ V (regulated), $f_s = 20$ kHz, and $C = 470$ μF. Calculate L_{min} that will keep the converter operating in a continuous-conduction mode if $P_o \geq 2$ W.

7-12 Buck-boost

$8 \leq V_d \leq 40$

$V_o = 15V$

$P_o \geq 2W$

$f_s = 20kHz$

$L_{min} = ?$

$C = 470\mu F$

$I_o = \frac{2}{15} = 0.133A$

$V_o = \frac{\phi V_d}{}$

$1-\phi$

$\frac{1-\phi}{\phi} = \frac{V_d}{V_o}$

$\frac{1}{\phi} - 1 = \frac{V_d}{V_o}$

$\frac{1}{\phi} = \frac{V_d}{V_o} + 1 = \frac{V_d + V_o}{V_o} \Rightarrow \phi = \frac{V_o}{V_d + V_o}$

at $V_d = 8V$

$\phi = \frac{15}{8+15} = \frac{15}{23} = 0.65$

at $V_d = 40V$

$\phi = \frac{15}{55} = 0.273$

smallest ϕ results in largest L_{min}.

7-47

$I_o = \frac{T_s V_o}{2L}(1-\phi)^2$

$L = \frac{T_s V_o}{2 I_o}(1-\phi)^2 = \frac{15}{2(20000)(0.133)}(1-0.273)^2$

$L = 1.49mH$