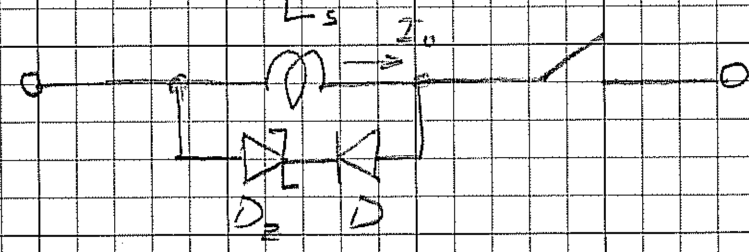
EECE 473 Power Electronics April 14, 2010

Midterm Exam

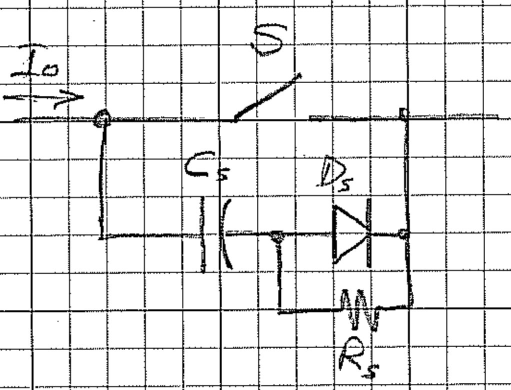
1. a) Snubber circuits protect devices against high di/dt and high dv/dt which are turn-on and turn off snubbers, respectively. A turn-on snubber is essentially an inductance insrted in series with the switching device and its value is calculated from:

$$L_s = V_s \left(\frac{di}{dt}\right)^{-1}_{dev}$$

So if the supply voltage is 100V and the allowa rate of rise of device $(di/dt)_{dev} = 10^8$ A/s, then $L_s = 1\ \mu H$. When the device is switched off a path for the current in L_s must be provided as shown:



The turn off snubber controls the rate of rise of voltage across a device by insrting a capacitance as shown:



When S turns off with a load current I_o The voltage rise across it controlled by C_s =

$$C_s = I_o \left(\frac{dV}{dt}\right)_{dev}^{-1}$$

For a current of 10 A and $(dV/dt)_{dev} = 10^5$ A/s
$C_s = 10^{-4} F = 100 \mu F$

b) BJT require a continuous current strong enough to cause the device to operate in the saturation region. Usually we over-drive the BJT by by a factor of 50 to 100% (ie. ODF = 0.5→1).

$$I_B = \frac{I_c}{\beta} ODF$$

To enhance turn-on we can shape the base current to provide a large initial pulse allowing for a quick charge of the base to emitter capacitance (C_{BE}).

MOSFETS require a voltage signal which is continuous and higher than the threshold voltage given in the gate-to-source characteristic. But the gate supply must also have strong current sourcing ability to charge the gate to source capacitance quickly. Current sink capability of the gate drive is also desirable to allow quick C_{GS} discharge and turn off of the MOSFET.

A GTO requires a positive current pulse to turn it on and a negative pulse to turn it off. The negative pulse usually has an amplitude equal to about one quarter of the main thyristor current. The GTO is sensitive to noise appearing between gate and cathode and to minimize sensitivity a continuous positive current, but small, is usually supplied.

There are two stages in a drive circuit: the signal processing stage to generate the current or voltage signal wave and a second interface stage to amplify the signal and apply it to the device. Frequently we need to isolate the device from the drive circuit using a signal transformer or optocoupler to generate identical signals driving devices with different common points.

2. a) When Q is turned on a voltage pulse appears across primary and is reflected on to secondary. A current will circulate on secondary and is limited by R_G; the current entering the thyristor gate and the voltage between gate and cathode should larger than I_{GT} and V_{GT} specified in the data sheet of the thyristor. The duration of the current pulse should longer than the minimum turn-on time of the thyristor; this is controlled by the turn-on time of the transistor Q. The resitance R_{GK} is to short noise appearing between gate and cathode and its value should much larger (10 times) than V_{GT}/I_{GT}. Diode D_2 is to prevent current from being extracted from gate when the magnetizing inductance is discharging. When Q is turned off the magnetizing inductance discharges its energy through D_1 and D_Z is used to control the discharge time. R_p is to limit the current through Q and the transformer is to provide isolation between the drive circuit and the thyristor voltage

b) The thyristor is subjected to 380V rms or $380 \times \sqrt{2} = 537.3V$ peak, So an appropriate selection would be the 2N6508. But if we want to keep a 20% safety margin for inadvertent overvoltages, then $537.3 \times 1.2 = 644.8V$ should be considered. So it seems safer to use the 2N6509.

To allow for a wide range of operation we will design for an $I_{GT} = 75mA$ ($-40°C$) and a gate trigger voltage of 1.5V (V_{GT}), So the gate-trigger resistance is $R_{GT} = 1.5/0.075 = 20\Omega$.

R_{GK} is selected to be much greater than R_{GT} so $R_{GK} = 220\Omega$.

Current on transformer secondary is:

$$I_s = 0.075 + \frac{1.5}{220} = 0.082A = 82mA$$

If we allow for 1V drop accross D_2, for a resistance $R_g = 22\Omega$ we obtain a secondary voltage of:

$$V_s = 1.5 + 1 + 22 \times 0.082 = 4.3V$$

c) Since the secondary voltage is well below the voltage supply of the driving transistor, then 1:1 turns ratio could be satisfactory. The number of turns is selected to be 4.

The transformer core area is given by:

$$A_c = \frac{V_p\, t_{on}}{N_p\, B_s} = \frac{4.3 \times 3\times10^{-6}}{4 \times 1.5} = 2.15\times10^{-6}\, m^2$$
$$= 2.15\ mm^2$$

A suitable wire is AWG 24 ($\simeq 0.5$ mm $\varnothing$) with maximum amperes of 0.577 A. So the opening of the core should be at least:

$$8 \times \frac{0.51^2}{4} \times \pi \times (2) \simeq 3.3\ mm^2$$

The T 6×3×4 would an opening of 7.07 mm², which would give plenty of room to make the turns.
This core has an area of $A_c = \frac{6-3}{2} \times 4 = 6\ mm^2$ and a core length $l_c = \left(\frac{6+3}{2}\right) \times \pi = 14.14$ mm.

d) The magnetizing inductance is given by:

$$L_\mu = \frac{\mu \times A_c N_p^2}{l_c} = \frac{4\pi}{10^7} \times \frac{4\times10^4 \times 6\times10^{-6}\times 16}{14.14\times10^{-3}} \Rightarrow$$

$$L_\mu = 341\,\mu H$$

The magnetizing current is: $I_\mu = \frac{V_p t_{on}}{L_\mu}$

$$I_\mu = \frac{4.3\times 3\times10^{-6}}{341\times10^{-6}} = 0.0378\,A$$

The primary current is $0.082\,A$, so the total current flowing in the transistor Q is:

$$I_c = 0.082 + 0.0378 = 0.12\,A = 120\,mA.$$

The value of R_p is determined using KVL:

$$V_{cc} = I_c R_p + V_p + V_{CE(SAT)} \Rightarrow$$

$$R_p = \frac{V_{cc} - V_p - V_{CE(SAT)}}{I_c} = \frac{12 - 4.3 - 0.5}{0.12}$$

$$= 60\,\Omega.$$

So a $R_p = 56\,\Omega$ is selected.

The current in the base needed to drive the transistor at the edge of saturation is $I_B = \frac{I_c}{\beta} = \frac{120}{75} = 1.6\,mA$

with a $ODF = 2$, $I_{BF} = 1.6\times2 = 3.2\,mA$.

So $R_B = \frac{5 - 0.0032\times100 - 0.7}{0.0032} \approx 1244\,\Omega$

$= 1.2\,k\Omega$

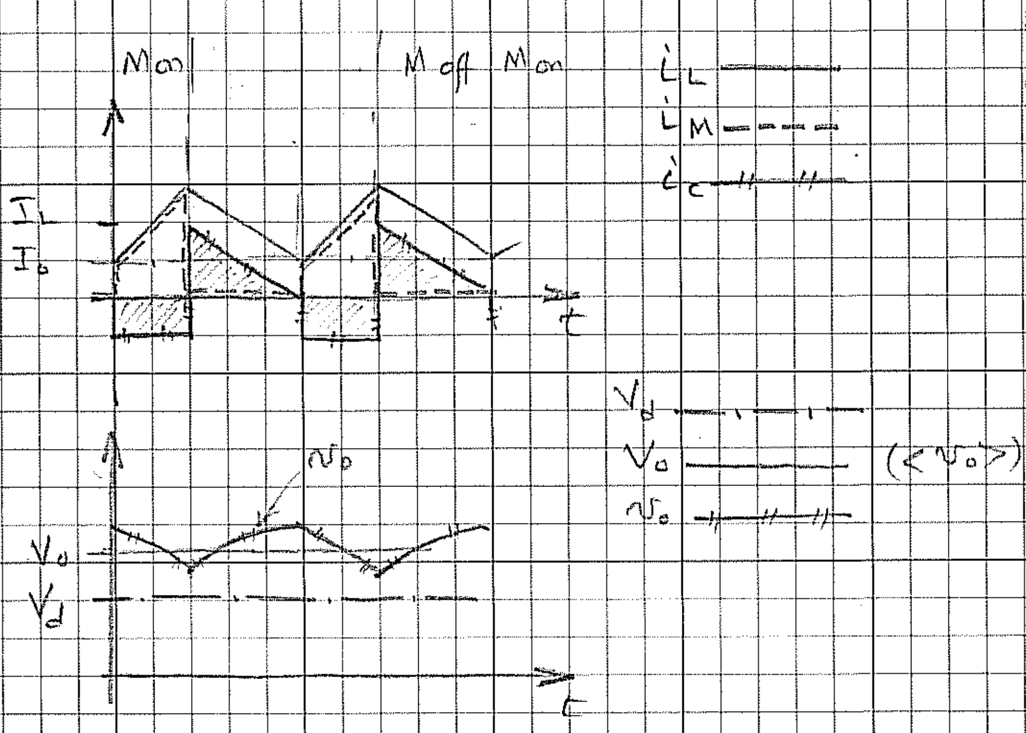
3.

a) The boost converter has two modes of operation:

i) When M is turned on the inductor L charges and i_L increases. Diode D is reversed biased by the capacitor (V_{DS} is negligible). The load is provided with energy from capacitor C and i_c decreases.

ii) When M is turned off the energy in the inductor is transfered to C and the load through the Diode. Note that $V_o > V_d$ since this is a boost converter.

The waveforms are shown below.



b) Range of duty cycle operation:

$V_d = 36 \qquad V_o \subset \{40, 80\}$

$D_1 = 1 - \frac{36}{40} = 0.1$ and $D_2 = 1 - \frac{36}{80} = 0.55$

$I_{LB} = \frac{\Delta I_L}{2} = \frac{V_d D}{2 f_s L}$ with $I_{LB} = \frac{I_o}{1-D}$

$$L = \frac{V_d (1-D) D}{2 I_o f_s} = \frac{36 \times (1-0.55)\, 0.55}{2 \times 2 \times 25 \times 10^3} = 89 \times 10^{-6}$$

We will use $L = 100\,\mu H$ to ensure continuous conducti

The capacitance is given by:

$$C = \frac{I_o D}{\Delta V_o f_s} = \frac{8 \times 0.55}{0.05 \times 80 \times 25 \times 10^3} = 44\,\mu F \; (\sim 50\,\mu F)$$

The peak transistor current is equal to the peak inductor current:

$$I_{M(peak)} = I_L + \frac{\Delta I_L}{2}$$

$$I_L = \frac{I_o}{1-D} = \frac{8}{1-0.55} = 17.8 A$$

$$\frac{\Delta I_L}{2} = \frac{0.55 \times 36 (1-0.45)}{2 \times 25 \times 10^3 \times 100 \times 10^{-6}} = 1.78 A$$

$$I_{M(peak)} = 19.6 A$$

The peak voltage is $80 + 1 + 0.05 \times 80 = 85V$

The IRF150 has a continuous current rating of 24A and back V_{DS} of 100V, at 100°C. The forward voltage drop is slightly less than 1 V ($I_{DS} \times R_{DS}$)!

The turn on time (delay plus rise) is 125ns and the turn off time is 300ns. So from power rating and switching speed the IRF150 is suitable.

c) This is a complementary drive circuit when A is high, Q_1 is turned on and the gate-source capacitance of MOSFET (M) is charged from supply V_{cc} via R_1; when A is low Q_2 becomes a low impedance path and C_{GS} of M discharges to ground. Diode D provides a path to discharge the capacitance of Q_1 (C_{BE}) when V_A goes low.

To have fast turn on time of the MOSFET (IRF150) we will allow an initial current pulse of 600mA. So:

$$R_1 = \frac{V_{cc} - V_{BE(SAT)}}{I_{C(max)}} = \frac{12 - 0.5}{0.6} = 19.7\Omega$$

We can select 22Ω, which is slightly higher. But we could also select an 18Ω resistor, which will give slightly higher current. This is possible because the current is a pulse and thus not continuous. To be sure we need to refer to the data sheet of the 2N2222A. The time needed to charge the capacitance to 110 nC is ≈ 110/0.64 = 172 ns.

R_2 is obtained from:

$$I_{cmax} = \frac{V_{GS}(o)}{R_2} \Rightarrow R_2 = \frac{12}{0.2} = 60\,\Omega$$

So R_2 is selected as $56\,\Omega$.

The value of R_B is obtained as follows:

- first calculate the base current of Q_1 with an ODF of 1.5

$$I_B = \frac{I_c}{\beta} \times ODF = \frac{600}{75} \times 1.5 = 12\ mA$$

$$\text{So} \quad R_B = \frac{12_{(V)} - 0.8}{12_{(mA)}} = \frac{12 \times 0.1}{} = 0.83\ k\Omega\ (820\,\Omega$$

This will give an ODF for Q_2 of:

$$ODF = \frac{\beta I_B}{I_c} = \frac{75 \times 12}{200} = 4.5$$

which is rather high. To avoid this we can have seperate base resistances for Q_1 and Q_2.