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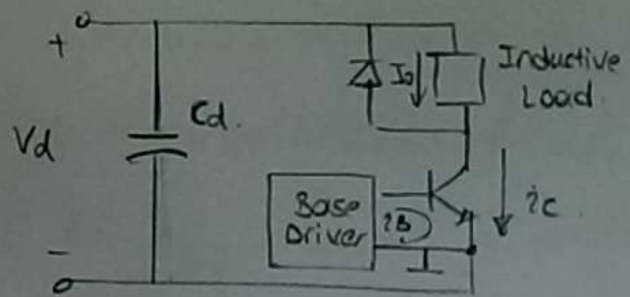
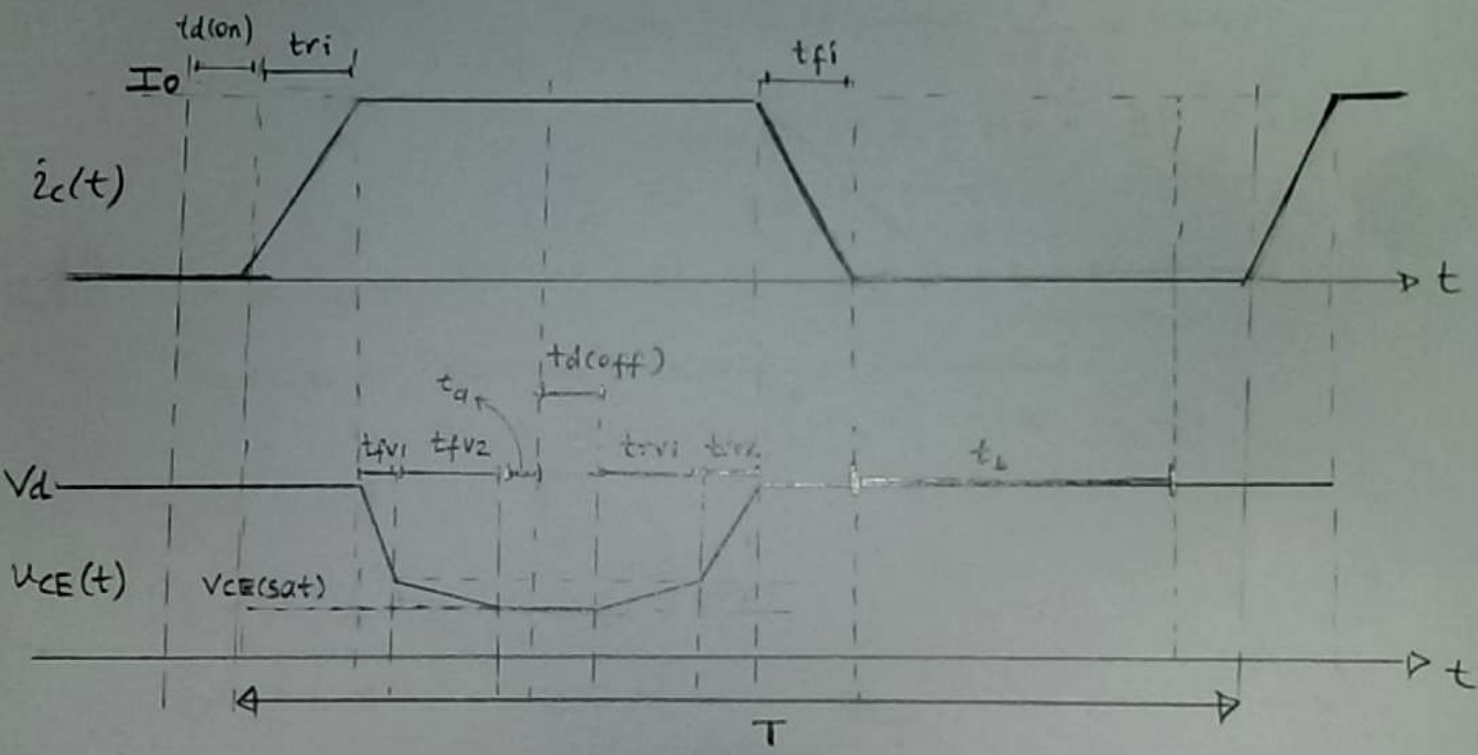
EE464 - Power Electronics 2

Assignment #4

1) Step down converter:





$$T = t_d(on) + t_{ri} + t_{fv_1} + t_{fv_2} + t_a + t_d(off) + t_{rv_1} + t_{rv_2} + t_{fi} + t_b$$

$$D = \frac{td(on) + tri + tfv1 + tfv2 + ta}{T} = 0.5$$

$$td(on) + tri + tfv1 + tfv2 + ta = td(off) + trv1 + trv2 + tfi + tb.$$

$$\underline{t_a = t_b}$$

$\rightarrow T = 2 \times [100n + 200n + 50n + 50n + t_a]$

$\underline{T = 800n + 2ta}$

$$E_{(on)} = \frac{I_o}{2} \cdot V_d \cdot t_{ri} + \frac{V_d + V_{CE(sat)}}{2} I_o \left(t_{fv_1} + t_{fv_2} \right)$$

Note that, the voltage fall is assumed to be linear.

$$E_{(off)} = \frac{V_d + V_{CE(sat)}}{2} \cdot I_o \cdot \left(t_{rv_1} + t_{rv_2} \right) + \frac{I_o}{2} \cdot V_d \cdot t_{fi}$$

$$E_{(conduction)} = I_o \cdot V_{CE(sat)} \cdot \left(t_a + t_{d(off)} \right) = 80 \left(\frac{1}{2f} - 300n \right)$$

$$E_{(on)} = E_{(off)} = 604 \mu J$$

a.) $P_{avg} = f \left(E_{(on)} + E_{(off)} + E_{(conduction)} \right) = f \times 1.208m + 40 + f \times 24\mu = 40 + f \times 1232\mu$

$$P_{avg} = 40 + f \times 1232\mu$$

b) $P_{loss,max} = \dfrac{T_J - T_a}{R_{\theta J\text{-}a}} = \dfrac{150-25}{1\ C°/W} = 125\ W$

$P_{avg} = 40 + f \times 1232\mu = 125 \longrightarrow f_{max} = 68994\ Hz \cong 69\ kHz$

max permissible switch frequency $\longrightarrow$

c) $E_{conduction} = E_{switching}$

$(t_a + t_{d(off)})\ I_o . V_{CE(sat)} = 2 \times \left[\dfrac{V_d + V_{CE(sat)}}{2} . I_o (t_{rv1} + t_{rv2}) + \dfrac{I_o}{2} V_d t_{fi} \right]$

$80 . \left(\dfrac{1}{2f} - 300n\right) = 2 \times 604\mu J$

$\dfrac{1}{2f} - 300n = 15.1\mu \longrightarrow \dfrac{1}{2f} = 15.4\mu$

$f = 32467.5\ Hz \cong 32.5\ kHz$

d) $P_{diode,avg} = I_o . V_f . (1-d) = 40 . 1 . 0.5 = 20\ W$

$P_{total,loss} = P_{diode,avg} + P_{switching} + P_{conduction}$

$= 20 + 40 + f \times 1232\mu \Big|_{f=32.5k} = 100W$

$P_o = I_o V_o\ ,\ V_o = DV_{in} = 50V$

$P_o = 40 \times 50 = 2000W$

$\eta = \dfrac{P_o}{P_o + P_{loss}} = 0.95$

e) $P_{total,loss} = 20 + 40 + f \times 1232\mu \Big|_{69kHz} = 145\ W$

$\eta = \dfrac{P_o}{P_o + P_{loss}} = \dfrac{2000}{2145} = 0.93$

e) Continue...

Diode power dissipation is constant while switch power dissipation is directly proportional with the switching frequency. Therefore. Increased frequency causes a drop in the efficiency.

$$P_{out} = 2000\ W \quad , \eta = \frac{P_{out}}{P_{out} + P_{loss}}$$

$$P_{loss,min}\Big|_{f=0} = 60\ W \qquad \eta_{max} = \frac{2000}{2000+60} = 0.971$$

Efficiency is less than 97.1 %.

As indicated before, if the switching frequency is decreased, the efficiency increases. However, for lower frequencies, the current ripple becomes significant. So, for a acceptable current ripple (%1) inductance, switching frequency and efficiency should be optimized.

$$\Delta I_L = \frac{1}{L}(V_d - V_o)\, d\, T_s = \frac{1}{L}\frac{V_d(1-d)}{f_s} d \Rightarrow L f_s = 62.5 \quad \text{for } \Delta I_L = 0.4A$$

%1 ripple

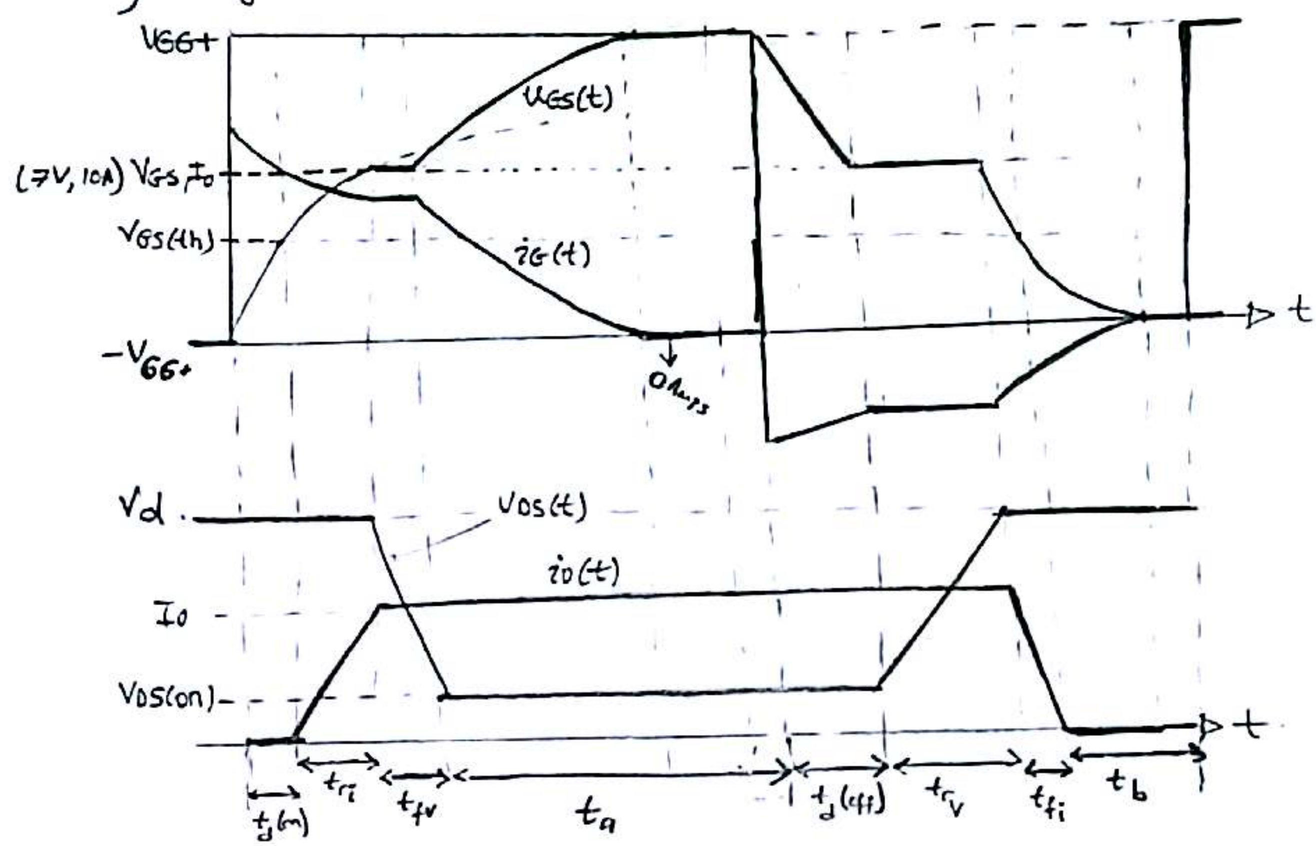
In market, 10 mH inductances can be found easily, so for this inductance value, $f_s = 6.25\, kHz$.

$$P_{loss}\Big|_{f_s = 6.25k} = 67.7W \Rightarrow \eta = 96.7\%$$

As a result, for such a converter whose efficiency is 97.1% maximum, 96.7% efficiency is acceptable and ripple is kept as also acceptable.

2) $V_d = 300V$, $I_o = 10A$, $V_{GG} = \pm 15V$ % 50 duty cycle, $R_g = 50\Omega$, $V_{GS(th)} = 4V$, $C_{gs} = 1nF$

a) $C_{gd} = 150pF$, $R_{ds(on)} = 0.5\Omega$



$$T = t_d(on) + t_{ri} + t_{fv} + t_a + t_d(off) + t_{rv} + t_{fi} + t_b$$

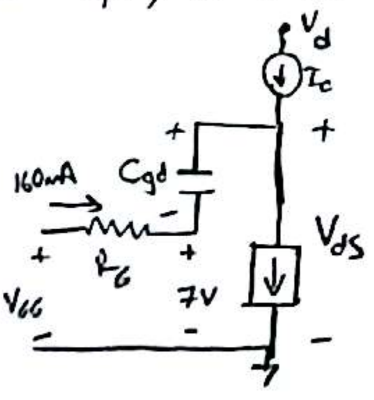
for $t_d(on)$, $V_{GS}(t) = V_{GG} - 2V_{GG}\, e^{-t/\tau}$, $\tau = R_g\,(C_{gd} + C_{gs}) = 57.5\,ns$

$$V_{GS}(t) = V_{GS(th)} = 4V = 15 - 30\,e^{-t_{on}/57.5ns}$$

$$\Longrightarrow \boxed{t_{on} = 57.7\,ns}$$

for t_{ri}, $V_{GS} = 7V = 15 - 30\,e^{-(t_{on}+t_{ri})/57.5ns} \Rightarrow \boxed{t_{ri} = 18.3ns}$

for t_{fv}, it is assumed that the V_{DS} decreases linearly



$$V_{ds} = \underbrace{V_{GS}(th)}_{7V} + V_{Cgd}, \quad V_{ds(on)} = I_o R_{ds(on)} = 5V$$

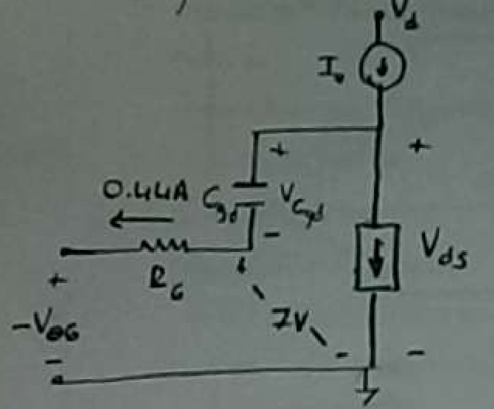
$$i_{C_{gd}} = C\frac{\partial V_{cgd}}{\partial t} = C\frac{\partial (V_{ds} - 7V)}{\partial t} = C_{gd}\frac{300V - 5V}{t_{fv}}$$

$$\boxed{t_{fv} = C_{gd}\frac{295V}{0.16A} = 276.6\,ns}$$

for $t_d(off)$, $V_{GS(t)} = -V_{GG} + 2V_{GG}e^{-t/\tau}$, $\tau = R_g(C_{gd}+C_{gs}) = 57.5ns$

$$7V = -15 + 30e^{-t_d(off)/\tau} \Rightarrow \boxed{t_d(off) = 17.8ns}$$

for t_{rv}, Voltage rise is assumed to be linear



$$V_{Cgd} = V_{ds} - 7V$$

$$i_c = C_{gd}\frac{\partial V_{Cgd}}{\partial t} = C_{gd}\frac{295V}{t_{rv}}$$

$$\Rightarrow \boxed{t_{rv} = 100.6ns}$$

for t_{fi}, $V_{GS}(t) = -15 + 22e^{-t/\tau}$, $\tau = 57.5ns$

$$V_{GS}(t_{fi}) = 4 = -15 + 22e^{-t_{fi}/\tau} \Rightarrow \boxed{t_{fi} = 8.43ns}$$

$$D = \frac{t_d(on) + t_{ri} + t_{fv} + t_a}{T} = 0.5$$

$$t_d(on) + t_{ri} + t_{fv} + t_a = t_d(off) + t_{rv} + t_{fi} + t_b$$

$$352.6ns + t_a = 126.8ns + t_b$$

$$t_b = t_a + 225.8ns$$

b) $f_s = 20kHz \Rightarrow T = 50\mu s \Rightarrow t_a = 24.65\mu s$, $t_b = 24.88\mu s$

$$E(ri) = \frac{I_o}{2} \cdot V_d \cdot t_{ri} = 27.45\mu J$$

$$E(fv) = I_o\left(\frac{V_d + V_{ds}(on)}{2}\right) t_{fv} = 421.8\mu J$$

$$E_{cond} = I_o V_{ds(on)} (t_a + t_d(off)) = 1.23mJ$$

$$E(rv) = I_o\left(\frac{V_d + V_{ds}(on)}{2}\right) t_{rv} = 153.4\mu J$$

$$E(fi) = \frac{I_o}{2} V_d t_{fi} = 12.6\mu J$$

$$\sum E = 1.845mJ$$

$$\boxed{P_{avg} = \frac{\sum E}{T} = 36.9W}$$