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SUBJECT - SMRC ASSIGNMENT - 1

Ques 1.

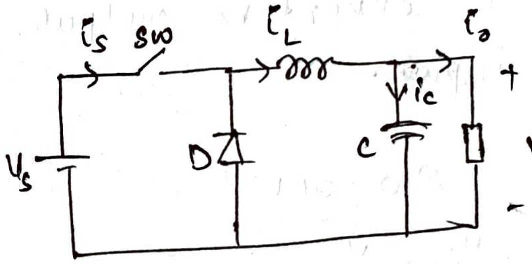
a) Role of L and C in Buck and Boost Converter

Role of L and C in Buck Converter

In Buck Converter, the inductor plays a important role to lower the input voltage.

As when SW → ON
D → OFF

$\boxed{V_L = V_{in} - V_o}$



SW → OFF
D → ON

$\boxed{V_L = -V_o}$

This opposing voltage V_L counteracts the voltage of the source and reduces the voltage on the load. At the same time inductor absorbs energy from the source and stores the energy in the form of a magnetic field.

- C → The capacitor is always being charged by the inductor, so it never has to support the load by itself. The inductor acts as a current source to keep the output capacitor charged.

In buck Converter, initially when

Sw → ON

Capacitor charges and stores energy.

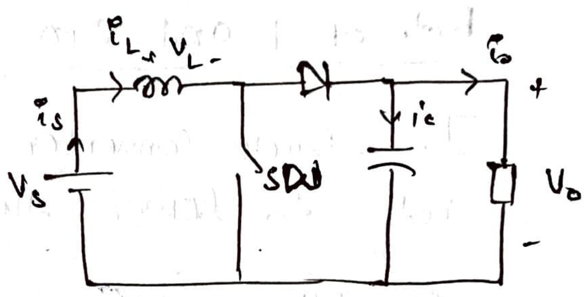
Sw → OFF

the inductor current flows throug the diode.

$$\boxed{i_c = i_L - i_o}$$

Role of L and C in Boost Converter

→ To reduce voltage ripple, filters made of capacitors are added to such type of converters output and input.



Sw → ON

$V_{in} = V_L$

$i_c = i_o$

Sw → OFF

$V_L = V_{in} - V_o$

$i_c = i_o - i_L$

In boost Converter the inductor current is always equals to the source i/p current.

$$\boxed{i_L = i_s}$$

→ When the switch is closed then the capacitor is able to provide the voltage and energy to the load. During this time, the blocking diode prevents the capacitor from discharging through the switch.

b) Size of L and C affected by increasing frequency.

Sol^n:- **Buck Converter**

SW → off

$V_L = -V_0$

$$\frac{L \Delta I}{(1-D)T} = V_0$$

$$\boxed{\Delta I = \frac{V_0(1-D)}{LF}}$$

When f ↑

∵ ΔI, ΔV → kept const (A/Q)

$$L = \frac{V_0(1-D)}{f \Delta I}$$

f ↑

L ↓

Hence size of induction is affected when we increase the frequency i.e, inversely proportional relation.

For C

$Q = C \Delta V$

$$Q = \frac{1}{2} \times \frac{\Delta I}{2} \times \frac{T}{2}$$

$$C = \frac{Q}{\Delta V}$$

$$\boxed{C = \frac{\Delta I}{8 \Delta V f}}$$

Hence f ↑, C ↓

Boost Converter

SW → ON

$V_L = V_{in}$ for 'L'

$$\frac{L \Delta I}{DT} = V_{in}$$

$$\boxed{L = \frac{DV_{in}}{F \Delta I}}$$

When f ↑

L ↓.

i.e, inverse relation.

For 'c'.

$Q = C \Delta V$

$Q = I_o \cdot T_{ON}$

$i_o T_{ON} = C \Delta V$

$$C = \frac{i_o DT}{\Delta V}$$

$$\boxed{C = \frac{i_o D}{\Delta V \cdot F}}$$

∴ f ↑

C ↓

Hence by inc. frequency size of inductor and capacitor should be choosen small.

Ques 2. Given.

$V_{in} = 24V$

$d = 0.8$

$f_s = 100KHz$

$C = 100\mu F$

$C \times ESR = 30\mu sec.$

$i_{L\,min} = 2.7\,A$

$i_{L\,max} = 3.3\,A$

R load.

Buck Converter

To find → i) L

ii) R

iii) V_o and $\Delta V_o\,(\%) = ?$

Sol^n

i)

$\Delta I = I_{L\,max} - i_{L\,min}$

$= 3.3 - 2.7$

$= 0.6A.$

Ist when sw → OFF

$V_L = V_o$

$\frac{L\Delta I}{(1-D)T} = DV_s$

$L = \frac{DV_s(1-D)}{f\Delta I} = \frac{0.5 \times 0.5 \times 24}{100k \times 0.6}$

$\boxed{L = 0.1mH}$

ii, iii) for R. and ΔV_o

$I = r_c \cdot C$

$300\mu = r_c \times 100\mu$

$\boxed{r_c = 0.3\,\Omega}$

↳ Electrolytic Cap is used for Calculating this

∴ At $r_c = 0.3\,\Omega$

$V_{or} = \Delta I_{Lr} \times r_c$

$I_{Lr} = \Delta I_{p-p}$

$= 0.6 \times 0.3$

$= 0.18\,V$

% peak to peak ripple in $V_o = \frac{0.18}{0.5 \times 24} = \frac{0.18}{12} \times 100$

$= 1.5\%$

$\boxed{\% V_{o\,p-p} = 1.5\%}$

$i_o = i_{L\max} - \frac{\Delta I}{2}$ or $i_{L\min} + \frac{\Delta I}{2}$

$\therefore i_o = 3.3 - \frac{0.6}{2} = 3A.$

$V_o = I_o \times R$

$R = \frac{12}{3} = 4\Omega$

$\therefore \boxed{R = 4\Omega}$

$V_o = ?$

$V_o = D V_{in}$

$= 0.5 \times 24$

$\boxed{V_o = 12V}$

Ques 3. $V_{ip} = 120V$ Buck Converter

$V_{op} = 24V$

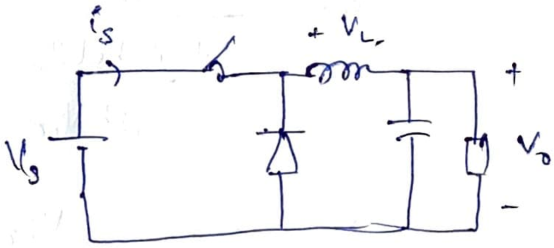
$D = 0.2$, $f_s = 40kHz$, $L = 0.48\,mH$

$I_o \rightarrow 0.5A.$

Soln: $V_{op} = DV_s$

$= 0.2 \times 120$

$= 24V$



$\Delta I_L = 5A.$

SW → off

$V_L = V_o$

$\frac{L \Delta I}{(1-D)T} = V_o$

$\Delta I = 2I_o$

$I_o = \frac{d(1-d)V_{in}}{2Lf_s}$

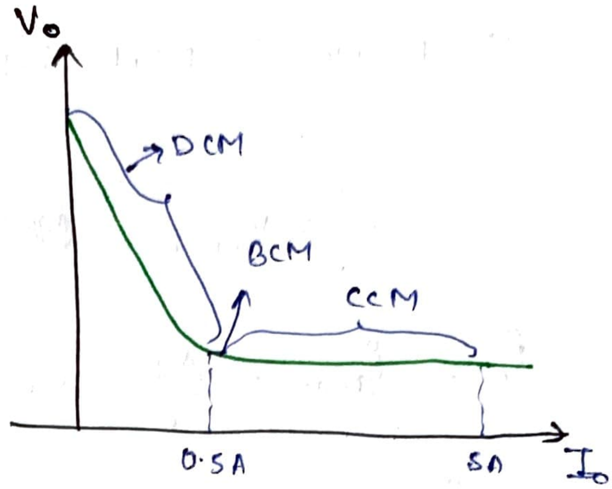
$I_o = \frac{0.2 \times 0.8 \times 120}{2 \times 40 \times 10^3 \times 0.48 \times 10^{-3}}$

$\boxed{I_o = 0.5A}$

for DCM

$$V_o = \frac{V_{in}}{1 + \frac{2 f_s L I_o}{d^2 V_{in}}}$$

I/o relation in DCM mode.



Under Boundary Condition

(Here BCM should obeys CCM equation and DCM equation).

$$I_o = \frac{\Delta I_L}{2} = \frac{d(1-d)V_{in}}{2 f_s L}$$

$$V_o = \frac{V_{in}}{1 + \frac{2 f_s L I_o}{d^2 V_{in}}}$$

$$= \frac{V_{in}}{1 + \frac{2 f_s L}{d^2 V_{in}} \frac{d(1-d)V_{in}}{2 f_s L}}$$

$$\boxed{V_o = d V_{in}}$$

Same equation valid for CCM mode.

Ques 4. Boost

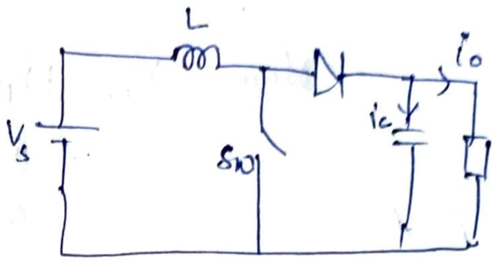
$V_{in} = 24V$, $D = 0.5$, $f_s = 100kHz$, $C = 100\mu F$,

$C \times ESR = 30\mu s$

$I_L = 2.7$ to 3.3 A

Soln:

i) $L = ?$



SW → ON

$V_S = V_L$

$$\frac{L\Delta I}{DT} = V_s$$

$$L = \frac{V_s D}{\Delta I f_s}, \quad \Delta I = I_{Lmax} - I_{Lmin}$$

$$= 3.3 - 2.7$$

$$= 0.6 A$$

$$= \frac{24 \times 0.5}{0.6 \times 100k}$$

$$\boxed{L = 0.2 mH}$$

ii) $R = ?$

$V_o = I_o \cdot R$

$$V_o = \frac{V_{in}}{1-D} = \frac{24}{1-0.5} = 48V$$

$$i_{max} = (i_L)_{avg} + \frac{\Delta I}{2} \Rightarrow i_{Lavg} = i_{max} - \frac{\Delta I}{2}$$

$$\frac{i_o}{1-D} = 3.3 - \frac{0.6}{2}$$

$$i_o = (1-D) \times 3$$

$$= 0.5 \times 3 = 1.5 A.$$

Now,

$$R = \frac{V_o}{i_o} = \frac{48 \times 2}{3} = 32\Omega$$

$$\boxed{R = 32\Omega}$$

iii) $\% \Delta V_{p-p} = ?$

As, $C \times ESR = 30 \mu sec$

$$\tau = r_c \times C$$

$$30\mu = r_c \times 100\mu$$

$$\boxed{r_c = 0.3\,\Omega}$$

Now, $V_{or} = i_{L max} \times 0.3$

$$= 3.3 \times 0.3$$

$$= 0.99\,V$$

$$\% \Delta V_{op-p} = \frac{0.99}{48} \times 100$$

$$\boxed{\% \Delta V_{op-p} = 2.0625\%}$$

Ques. Buck Converter, CCM design

$V_{in} = 40-56V$

$V_o = 12V$ $\quad f_s = 20kHz$

$I_o = 2-5A$ $\quad \tau = 50\mu sec.$

$\Delta V_{op-p} < 50mV$ $\quad$ i) $L = ?$ $\quad$ ii) $C = ?$

$\Delta I_{Lmax\,p-p} < 1A$

Soln: $V_o = D V_s$

$$12 = 48 \times D$$

$$D = 12/48 = 0.25$$

$$D_{min} = 12/56 = 0.214$$

in Buck D_{min} is taken for desirable condn,

$\because$ CCM mode given.

When sw $\rightarrow$ off

$$V_L = V_o$$

$$\frac{L \Delta I}{(1-D)T} = V_o$$

$$L = \frac{V_o(1-D)}{\Delta I f_s}$$

$$L = \frac{12(1-0.214)}{1 \times 20K}$$

$$\boxed{L = 471.48 \mu H}$$

ii) for C.

$I_{ESR} = r_c \cdot C$

$50\mu = r_c \cdot C$

$\Delta V_{op-p} = 50mV$

$Q = C\Delta V$

$$\frac{1}{2} \times \frac{T}{2} \times \frac{\Delta I}{2} = C\Delta V$$

$$C = \frac{T\Delta I}{8\Delta V}$$

$$C = \frac{1 \times 1}{20K \times 8 \times 50m}$$

$$\boxed{C = 125 \mu F}$$

As, $C > 20\mu F$ → ∴ We use electrolytic capacitor

∴ $I = r_c \times C$

$50\mu = r_c \times 125\mu$

$$\boxed{r_c = 0.4 \Omega}$$

$V_{or} = \Delta I \times r_c$

$= 1 \times 0.4$

$= 0.4 V > 50mV$

So our ripple won't be satisfied.

Hence, $I_{Lr} \cdot r_c = 50mV$

$1 \times r_c = 50mV$

$$\boxed{r_c = 50m\Omega}$$

Now, $\tau = r_c \cdot C$

$50\mu s = 50m \times C$

$$\boxed{C = 1mF}$$

Ques 6. IRF540 MBR10100 $\rightarrow V_r = 0.2$, $r_d = 60m\Omega$

$I_o = 5A$ $r_L = 30m\Omega$ $V_{in} = 48V$ $d = 0.28$

$r_s = 44m\Omega$ Buck CCM design.

Sol^n:-

$$V_o = [dV_{in} - (1-d)V_r] - [r_L + d r_s + r_d(1-d)]i_o$$

$$= [0.28 \times 48 - (1-0.28)0.2] - [0.03 + 0.28 \times 0.044 + 0.06(1-0.28)] \times 5$$

$$= 13.296 - 0.4276$$

$$\boxed{V_o = 12.8684\ V}$$

Ques 7. $R_g = 22\Omega$, $V_T = 3.5V$, $I_{ds} = 48A$, $V_{gs} = 7.5V$

i) Switching Power loss in MOSFET

ii) Conduction Power loss in MOSFET

iii) diode Power loss = ?

Sol^n:- i) Switching power loss = ?

$$E = P \times t$$

$$P = E \times f$$

$$= [E_{ON} + E_{OFF}] \times f$$

Energy loss during ON state

$$= V_{in} \cdot I \left[t_r + \frac{V_{in} - V_{dsr}}{V - V_{gsr}} \cdot \frac{R_g \cdot C_{rss2}}{2} \right]$$

IRF540

$\rightarrow r_s = 44m\Omega$, $C_{gd1} = 500pF$, $C_{gd2} = 150pF$, $C_{gs1} = 2500pF$, $C_{gs2} = 1900pF$, $C_{ds1} = 1200pF$, $C_{ds2} = 500pF$

MBR 10100 → $V_r = 0.2\text{ V}$, $r_d = 60\text{ m}\Omega$

$$E_{ON} = \frac{1}{2} V_{in} (t_2 + t_3)(I + I_R) + \frac{1}{2} V_{in} \cdot I \cdot t_4$$

$$t_2 = R_g C_{iss2} \ln \left(\frac{V - V_T}{V - V_{gscr}} \right)$$

$$C_{iss2} = C_{gd2} + C_{ds2} \longrightarrow \text{ON Case}$$

$$= (1900 + 150)\text{ pF}$$

$$\boxed{C_{iss2} = 2050\text{ pF}}$$

$$I_{ds} = \frac{\beta}{2} (V_{gs} - V_T)^2$$

$$48 = \frac{\beta}{2} (7.5 - 3.5)^2$$

$$\overset{3}{\cancel{48}} = \frac{\beta}{2} \times \cancel{16}$$

$$\boxed{\beta = 6}$$

At $I_{ds} = I_o$, $V_{gs} = V_{gscr}$

$$5 = \frac{6}{2} [V_{gscr} - 3.5]^2$$

$$\sqrt{\frac{10}{6}} = V_{gscr} - 3.5$$

$$1.291 + 3.5 = V_{gscr}$$

$$\boxed{V_{gscr} = 4.79\text{ V}}$$

As $R_g = 22\,\Omega$ which is low ∴ We Consider

$V_{gs} = V$

$$t_2 = 22 \times 2050 \times 10^{-12} \ln \left[\frac{7.5 - 3.5}{7.5 - 4.79} \right]$$

$$\boxed{t_2 = 17.56\text{ nsec}}$$

$t_3 \rightarrow$ reverse recovery time.

As A/o diode do not have any reverse recovery process.

$\therefore \boxed{t_3 = 0}$ and $\boxed{I_R = 0}$

$$t_4 \approx \left(\frac{V_{in} - V_{dscr}}{V - V_{gscr}}\right) R_g C_{rss2}$$

$$t_4 \approx \left(\frac{V_{in}}{V - V_{gscr}}\right) R_g C_{rss2}$$

$C_{rss2} = C_{gd2}$
$= 150\,pF$

$$t_4 \approx \left(\frac{48}{7.5 - 4.79}\right) \times 22 \times 150 \times 10^{-12}$$

$$\boxed{t_4 = 58.45\ n\sec}$$

$$E_{ON} = \frac{1}{2} V_{in}(t_2 + t_3)(I + I_R) + \frac{1}{2} V_{in} I \cdot t_4$$

$$= \frac{1}{2} \times 48\,(t_2) \cdot I + \frac{1}{2} V_{in} I t_4$$

$$= \frac{1}{2} \times 48 \times 17.56\,n \times 5 + \frac{1}{2} \times 48 \times 5 \times 58.45\,n$$

$$\boxed{E_{ON} = 9.121\ \mu J}$$

Now, $E_{OFF} = \frac{1}{2} V_{in} I\,(t_2 + t_3)$

$$t_2 = \frac{(V_{in} - V_{dscr}) R_g C_{gd}}{V_{gscr}} \approx \frac{V_{in} R_g C_{gd}}{V_{gscr}}$$

Here
$C_{gd} = C_{gd2}$

$$t_2 = \frac{48 \times 22 \times 150 \times 10^{-12}}{4.79}$$

$$\boxed{t_2 = 33.06\ n\sec}$$

$$t_3 = R_g C_{iss2} \ln \frac{V_{gscr}}{V_T}$$

$$= 22 \times 2400 \times 10^{-12} \ln\left(\frac{4.79}{3.5}\right)$$

$$\boxed{t_3 = 16.56 \text{ nsec}}$$

Off Case

$$C_{iss2} = C_{gs2} + C_{ds2}$$
$$= 1900 + 500$$
$$= 2400 \text{ pF}$$

$$E_{OFF} = \frac{1}{2} \times 48 \times 5 \times (33.06n + 16.56n)$$

$$\boxed{E_{off} = 5.954 \mu J}$$

$$\text{Total Energy} = E_{ON} + E_{OFF}$$
$$= (9.121 + 5.954) \mu J$$
$$= 15.075 \mu J$$

$$\text{Power loss} = (\text{Total Energy}) \times f$$
$$= 15.075\mu \times$$

ii) Conduction power loss in MOSFET,

$$= V_{ds(ON)} \cdot I_{DS(ON} \quad \text{or,}$$
$$= I_{ds}^2 \cdot R_s$$
$$= I_{ds}^2 \cdot r_s$$
$$= (48)^2 \times 44m$$

$$\boxed{\text{Cond}^n \text{ loss} = 101.376 \text{ W}}$$

iii) Diode power loss

$$P_{diode} = I_{drms}^2 \cdot r_d + I_{davg} \cdot V_r$$

$$I_{davg} = (1-d) I_o$$
$$I_{davg} = (1-0.28) \times 5$$
$$= 3.6 \text{ A}$$

$$I_{drms} = \sqrt{1-D} \cdot I_o$$
$$= \sqrt{1-0.28} \times 5$$
$$= 4.24 \text{ A}$$

$$\therefore P_{diode} = (4.24)^2 \times 0.06 + 3.6 \times 0.2$$
$$\boxed{P_{diode} = 1.799 W}$$

Ques 8. $V_o = 12V \rightarrow I_o = 3A$ | $r_d = 60 m\Omega$, $r_L = 30 m\Omega$

$V_{in} = 40V$ | $r_s = 44 m\Omega$ $V_r = 0.2V$

i) $D = ?$ ($r, V_r \rightarrow$ ignored)

Soln-

$$V_o = [d V_{in} - (1-d) V_r] - [r_L + d r_s + (1-d) r_d] I_o$$
$$12 = [40d - (1-d) \cdot 0] - [0.03 + 0.044 \times d + (1-d) 0.06]$$
$$12 = 40d - [0.03 + 0.044d + 0.06 - 0.06d] \times 3$$
$$12 = 40d - [0.09 - 0.016d] 3$$
$$12 = 40d - 0.27 - 0.048d$$
$$12.27 = 39.952d$$
$$\boxed{d = 0.307}$$

ii) $D = ?$ [with all r, and V_r included]

$$V_o = [d V_{in} - (1-d) V_r] + [r_L + d r_s + (1-d) r_d] I_o$$
$$= [40d - (1-d) \cdot 0.2] + [0.03 + 0.044d + (1-d) 0.06] 3$$
$$12 = 40d - 0.2 + 0.2d - 0.27 - 0.048d$$
$$12.47 = 40.152d$$
$$\boxed{d = 0.31}$$

Ques 9. $V_{in} = 10.5$ to $12.5\,V$

$V_o = 36V$

$I_o = 1$ to $3A$

$\Delta V_{o,p\text{-}p} \le 200\,mV$

$\Delta I_{p\text{-}p} < 1A$

$f_s = 40\,kHz$

Boost Converter.

$L = ?,\ C = ?$

$\tau = r_c \cdot C = 30\,\mu sec.$

Sol^n: In Boost

$$V_o = \frac{V_{in}}{1-D}$$

$$D_{max} = \frac{V_o - V_{inmin}}{V_o}$$

$$= \frac{36 - 10.5}{36}$$

$$\boxed{D_{max} = 0.707}$$

$$D_{min} = \frac{V_o - V_{imax}}{V_o}$$

$$= \frac{36 - 12.5}{36}$$

$$\boxed{D_{min} = 0.652}$$

We use $D = d_{min}$

$\therefore$ $V_{in\,max}$ is used.

SW → ON

$$V_L = V_s$$

$$\frac{L \Delta I}{DT} = V_s$$

$$L = \frac{V_s D}{\Delta I \cdot f}$$

$$= \frac{12.5 \times 0.652}{1 \times 40K}$$

$$\boxed{L_{min_1} = 203.75\,\mu H}$$

Now, we find the Lmin by using the concept of dmin and dmax ≥ 1/3.

$d_{min} = 0.652$, $d_{max} = 0.708$.

$\therefore$ $D = 0.33 \not< d_{min}, d_{max}$.

$\therefore$ D_{min} and $D_{max} > 1/3$.

$\therefore$ We use $d_{min} = 0.652$.

<u>for CCM cond^n</u>

$$(i_L)_{avg} \geq \frac{\Delta I}{2}$$

$$\frac{i_o}{1-D} = \frac{DV_s}{2LF}$$

$$i_{o\,min} = \frac{D(1-D)V_s}{2LF}$$

$$1 = \frac{0.652\,(1-0.652)\,12.5}{2 \times L_{min2} \times 40K}$$

$$\boxed{L_{min2} = 35.45\ \mu H}$$

$$\therefore L = \max(L_{min1}, L_{min2})$$

$$= \max[203.75,\ 35.45]\ \mu H$$

$$\boxed{L = 203.75\ \mu H}$$

<u>for C.</u>

first we calculate 'c' by assuming it ideal and decide whether electrolytic cap is needed or not.

$$Q = C\Delta V$$

$$I_o \cdot T_{ON} = C\Delta V$$

$$C = \frac{I_o D}{\Delta V \cdot f}$$

As $\Delta V_{p-p_{max}} \leq 200mV$

↳ Using $I_{o max}$ and D_{max}.

$$C = \frac{I_o D}{\Delta V \cdot f}$$

$$C = \frac{I_{o max} D_{max}}{\Delta V \cdot f}$$

$$C = \frac{3 \times 0.708}{200 \times 10^{-3} \times 40k}$$

$$\boxed{C = 265.5 \mu F}$$

Value of Cap > $20 \mu F$

∴ We use electrolytic cap.

$$\Delta V = I_{Lmax} \cdot r_c$$

$$i_{Lmax} = (i_L)_{avg} + \frac{\Delta I}{2}$$

$$= \frac{i_o}{1-D} + \frac{DV_s}{2Lf}$$

$$= \frac{3}{1-0.708} + \frac{0.708 \times 12.5}{2 \times 203.75\mu \times 40k}$$

$$\boxed{i_{Lmax} = 10.81 A}$$

$$\therefore \Delta V = i_{Lmax} \cdot r_c$$

$$r_c = \frac{\Delta V}{i_{Lmax}} = \frac{200m}{10.81}$$

$$\boxed{r_c = 18.5 m\Omega}$$

$$\therefore \tau = r_c \cdot C$$

$$30\mu = 18.5m \times C$$

$$\boxed{C = 1621.6 \mu F}$$

Ques 10.

IRF 540 $\rightarrow r_s = 44m\Omega$ $r_c = 19m\Omega$

MUR 820 $\rightarrow$ $V_r = 0.5$ V , $r_d = 40m\Omega$.

$r_l = 50m\Omega$

$d = 0.5$ to 0.8

i) $V_{in} = 10.5$ V

$i_o = 1A$

$V_o = 36V$

Soln:- $V_o = \left(\frac{V_{in}}{1-D} - V_r\right) - I_o\left\{\frac{r_L + d r_s}{(1-d)^2} + \frac{r_d + d r_c}{1-d}\right\}$

$$36 = \left(\frac{10.5}{1-d} - 0.5\right) - 1\left\{\frac{50m + 44m d}{(1-d)^2} + \frac{40m + 19m d}{1-d}\right\}$$

$\boxed{d = 0.7218}$

ii) $V_{in} = 10.5$ V $V_o = 36$ V

$I_o = 3A$

$$V_o = 36 = \left(\frac{10.5}{1-d} - 0.5\right) - 3\left\{\frac{0.05 + 0.044d}{(1-d)^2} + \frac{0.04 + 0.019d}{1-d}\right\}$$

$\boxed{d = 0.753}$

iii) $V_{in} = 12.5$ V , $I_o = 1A$, $V_o = 36V$

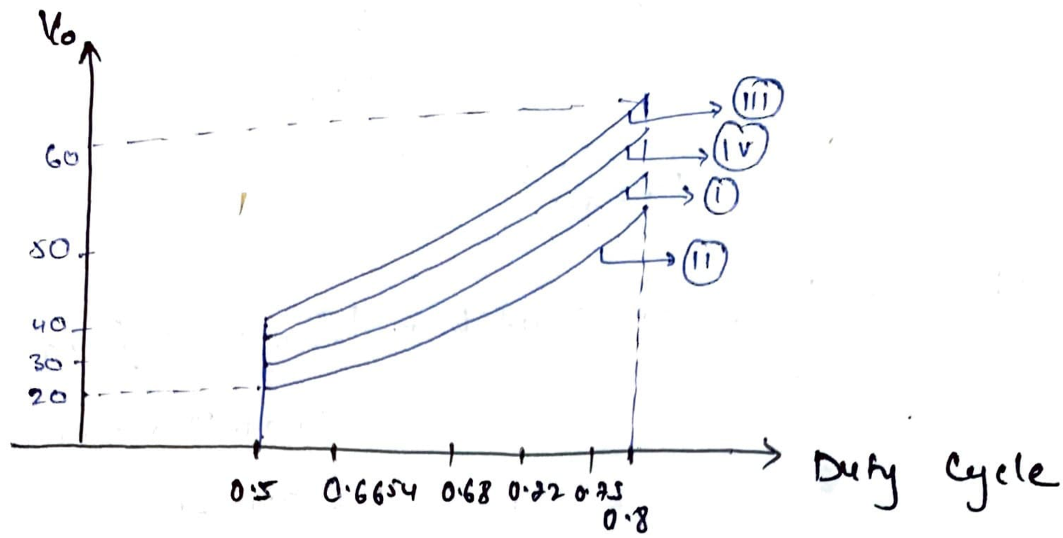
$$36 = \left(\frac{12.5}{1-d} - 0.5\right) - 1\left\{\frac{0.05 + 0.044d}{(1-d)^2} + \frac{0.04 + 0.019d}{1-d}\right\}$$

$\boxed{d = 0.6654}$

iv) $V_{in} = 12.5$ V , $I_o = 3A$, $V_o = 36V$

$$36 = \left(\frac{12.5}{1-d} - 0.5\right) - 3\left\{\frac{0.05 + 0.044d}{(1-d)^2} + \frac{0.04 + 0.019d}{1-d}\right\}$$

$\boxed{d = 0.6825}$



Ques 11.

$V_o = 36V$

$I = 3A$

$V_{in} = 12V$

i) Conduction loss in switch and diode.

Sol^n.-

Conduction loss in switch $= [I_{switch\,(rms)}]^2 \cdot r_s$

$$[I_{sw\,(rms)}]^2 = \left(\frac{I_o}{1-d}\right)^2 \times \frac{dT_s}{T_s}$$

$$I_{sw\,(rms)} = \frac{\sqrt{d}}{1-d} I_o$$

$$V_o = \frac{V_{in}}{1-d} \Rightarrow 1-d = \frac{V_{in}}{V_o}$$

$$d = 1 - \frac{12}{36}$$

$$\boxed{d = 2/3}$$

$$I_{sw\,(rms)} = \frac{3}{1-2/3}\sqrt{2/3} = 7.34A.$$

$$I_{diode\,(avg)} = I_o = 3A$$

$$I_{diode\,(rms)} = \sqrt{1-d}\ \frac{I_o}{1-d} = \frac{I_o}{\sqrt{1-d}}$$

$$= \frac{3}{\sqrt{1-2/3}} = 5.2\,A.$$

Conduction loss in switch $= [I_{sw\,(rms)}]^2 \times r_s$

$= (7.34)^2 \times 0.044$

$= 2.37\ W$

Conduction loss of Diode $= (I_{diode\,rms})^2 \times r_d + I_{diode\,avg} \times V_r$

$= (5.2)^2 \times 0.04 + 3 \times 0.5$

$= 2.58\ W$

ii) Switching losses in Switch

$$E_{OFF} = \frac{1}{2} V_o \frac{I_o}{1-d} (t_2 + t_3)$$

$$t_2 \cong \frac{V_o}{V_{gscr}} R_g C_{gd} \quad \rightarrow \quad C_{gd} = C_{rss2}$$

$$t_3 = R_g C_{iss2} \ln\left(\frac{V_{gscr}}{V_T}\right) \qquad C_{iss2} = C_{gs2} + C_{ds2}$$

$C_{iss2} = 1900 + 500 = 2400\ pF$

let $R_g = 22\,\Omega$, $V_T = 3.5$, $V = 15\,V$, $I_{ds} = 48\,A$,

$V_{gs} = 7.5\,V$

$$I_{DS} = \frac{B}{2}(V_{GS} - V_T)^2$$

$$48 = B/_2\,(7.5 - 3.5)^2$$

$\beta/2 = 3.$

$I_o = \beta/2 \, (V_{gscr} - V_T)^2$

$3 = 3 \, (V_{gscr} - 3.5)^2$

$\boxed{V_{gscr} = 4.5 \text{ V}}$

$t_2 \approx \frac{V_o}{V_{gscr}} \times R_g \, C_{gd} = \frac{36}{4.5} \times 22 \times 150 \times 10^{-12}$

$\boxed{t_2 \approx 26.4 \text{ nsec}}$

$t_3 = R_g \, C_{iss2} \ln\left(\frac{V_{gscr}}{V_T}\right)$

$= 22 \times 2400 \times 10^{-12} \ln\left(\frac{4.5}{3.5}\right)$

$\boxed{t_3 = 13.26 \text{ nsec}}$

$E_{OFF} = \frac{V_o I_o}{2(1-d)} (t_2 + t_3) = \frac{36 \times 3}{2(1-2/3)} (13.26 + 26.4) \times 10^{-9}$

$\boxed{E_{OFF} = 6.424 \, \mu J}$

$E_{ON} = \frac{V_o I_o}{1-d} \left[\tau_F - \frac{V_o - V_{dscr}}{V - V_{gscr}} \frac{R_g \, C_{rss2}}{2} \right]$

$C_{rss2} = C_{gd2} = 150 \text{ pF}$

$\tau_F = Q \times I \quad \therefore \boxed{\tau_F = 20 \text{ nsec}}$

$E_{ON} = \frac{36 \times 3}{1-2/3} \left[20 \times 10^{-9} - \frac{36 - 0}{15 - 4.5} \times \frac{22 \times 50 \times 10^{-12}}{2} \right]$

$\boxed{E_{ON} = 4.64 \, \mu J}$

$E = E_{ON} + E_{OFF}$

$\boxed{E = 11.064 \, \mu J}$

Switching losses in switch $= E \times f_s$

$= 11.064 \times 40 \times 10^3 \times 10^{-6}$

$= 0.44\ W.$

iii) Conduction loss in inductor

$r_d = 50m\Omega$

Conduction loss in inductor $= (I_{Lrms})^2 \times r_c$

$(i_{Lrms})^2 = \left(\frac{I_o}{1-d}\right)^2 \times \frac{T_s}{T_s}$

$i_{L\,rms} = \frac{I_o}{1-d} = \frac{3}{1-2/3} = 9A.$

$\therefore$ Cond^n loss in inductor $= (9)^2 \times 0.05$

$= 4.05$ Watt

iv) Conduction loss in Capacitor

$I_{crms} = \left(\left(\frac{I_o}{1-d}\right)^2 \times \frac{1-d/T_s}{T_s}\right)^{1/2}$

$= I_o\left(\frac{d}{1-d}\right) = 3\left(\frac{2/3}{1-2/3}\right) = 6A.$

$(I_{crms})^2 = \frac{(3)^2}{1} \times \frac{dT_s}{T_s} + \frac{(6)^2}{1} \times \frac{(1-d)\cancel{T_s}}{\cancel{T_s}}$

$\boxed{(I_{crms})^2 = 4.24A}$

$\therefore$ Conduction loss in Capacitor $= (I_{crms})^2 \times r_c$

$= (4.24)^2 \times 19 \times 10^{-3}$

$= 0.342$ Watt

Que 12. Buck Converter

36V/5V, 10A   60V, 25A, 40mΩ → out of stock then 300V, 75A, 120mΩ is used.

Ans: Reason

i) The ON Resistance of MOSFET increases with current level.

ii) The ON Resistance of MOSFET inc. with junction temperature.

iii) For the same current level, the MOSFET which are rated for higher voltage level will have higher switch ON resistance. Here we have example for the o/p current of 10A, the MOSFET which are substituted for 60V, 25A, 40mΩ rating is 300V, 75A, 120mΩ. Hence $R_{ds(ON)}$ increases and causes heating in the MOSFET. The variation of $R_{ds(ON)}$ with current is more sharper in the case of High Voltage MOSFET and temperature variation is more drastic in case of High Voltage MOSFET.

Here lets say for 60V, 25A, 40mΩ MOSFET, we need to apply V_{GS} = 15V then for turn ON MOSFET of rating 300V, 75A, 120mΩ MOSFET, we need to apply more than 15V but ckt specification not changed. Hence $R_{ds(ON)}$ will be more for High rating MOSFET and MOSFET will burn-out due to continuous heating.

Ques 13. 12V to 120V dc converter

$I_o = 0.5\,A$

Designed → Boost DC-DC

D → 0 to 1

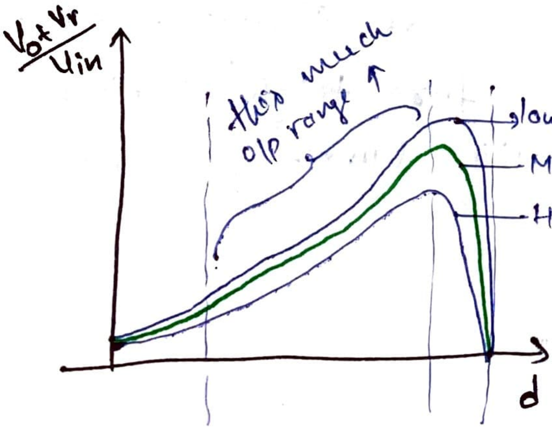
$V_{omax} = 50V$

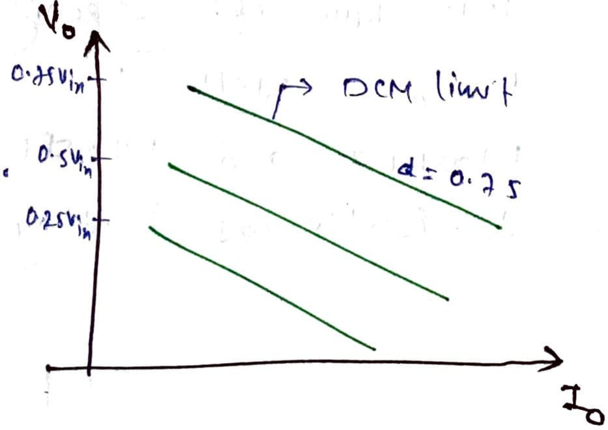
Ans:- for ideal Boost Converter

$$\boxed{V_o = \frac{V_{in}}{1-d}}$$

Here, she didn't realise that gain of the V_o/V_{in} can be increased upto 4 to 5 and hence she got the o/p voltage as 50V but not the 120V. and if we increase the duty ratio to increase the gain of the V_o/V_{in} the o/p voltage drop down to zero which can be very well seen from the graph. So the mistake done by her is that she used Boost topology but she didn't realises or consider what can be possible gain she can get. Hence she didn't got 120V as o/p.

$$\therefore V_o = \left(\frac{V_{in}}{1-d} - V_r\right) - I_o\left[\frac{r_d + d r_s}{(1-d)^2} + \frac{r_d + d r_c}{1-d}\right]$$





Ques 14. $V_{in} = 120V$ $\quad I_o = 0.5A$

$V_o = 24$ $\quad$ Buck Converter

$D = 0.2$ $\quad$ DCM or CCM = ?

$f_s = 20kHz$

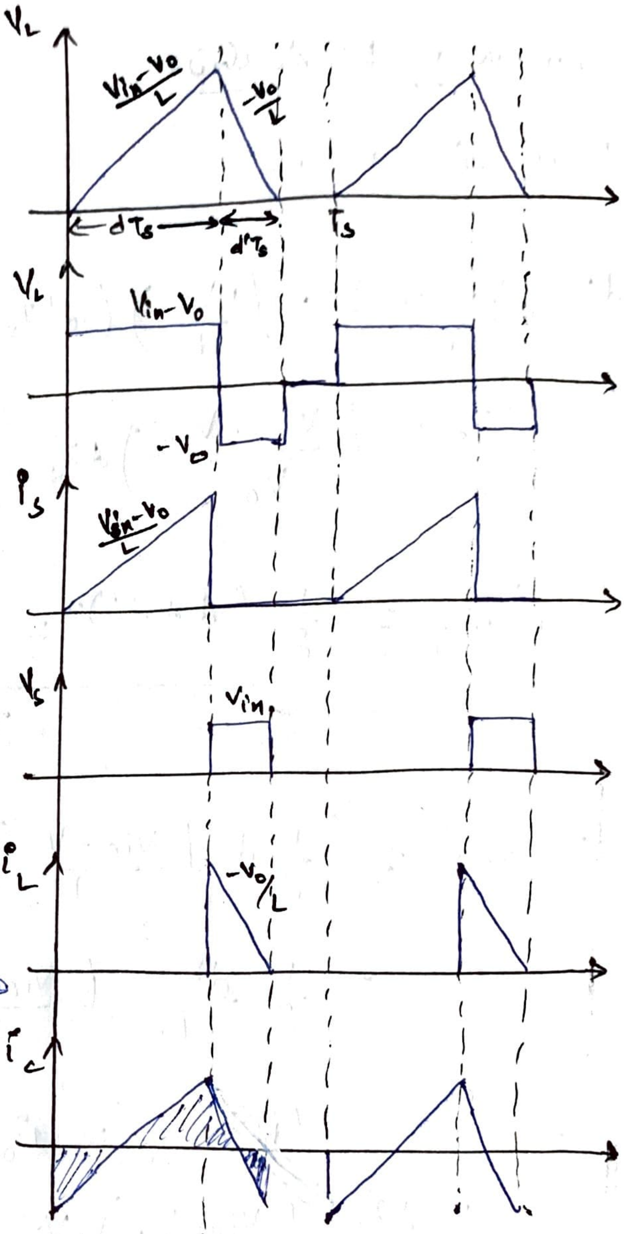
$L = 0.48 mH$

Soln:-

$V_o = DV_{in}$

$= 0.2 \times 120$

$= 24V$



$L_{given} = 0.48 mH$

$V_L = V_o \rightarrow$ off

$$\frac{L\Delta I}{(1-D)T} = V_o$$

$$\Delta I = \frac{V_o(1-D)}{Lf}$$

$$\therefore i_o = \frac{\Delta I}{2}$$

$$i_o = \frac{V_o(1-D)}{2Lf}$$

$$L_{critical} = \frac{V_o(1-D)}{2 i_o f}$$

$$= \frac{24 \times (1-0.2)}{2 \times 0.5 \times 20K}$$

$$\boxed{L_{critical} = 0.96 mH}$$

$L_{given} < L_{critical}$,

$\therefore$ Discontinuous Condn.

$\therefore$ Converter is in DCM mode.

$$\therefore V_o = \frac{V_{in}}{1 + \frac{2 f_s L i_o}{d^2 V_{in}}}$$

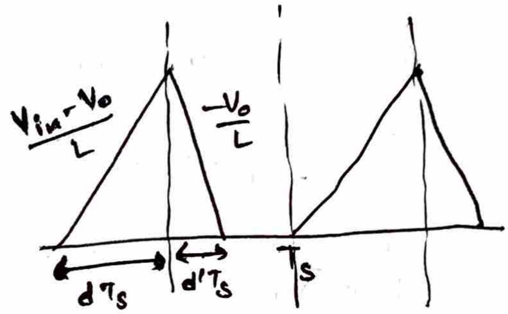
$$V_o = \frac{120}{1 + \frac{2 \times 20k \times 0.48m \times 0.5}{(0.2)^2 \times 120}}$$

$$\boxed{V_o = 40V}$$

Formula Derivation

Buck in DCM

$$dT_s\left(\frac{V_{in}-V_o}{L}\right) = \left(\frac{+V_o}{L}\right)(d'T_s)$$



$$d'T_s = \left(\frac{V_{in}-V_o}{V_o}\right) dT_s$$

$$(i_L)_{avg} = \frac{\frac{1}{2}(d+d')T_s \cdot \left(\frac{V_{in}-V_o}{L}\right) dT_s}{T_s}$$

$$(i_L)_{avg} = \frac{1}{2} d \left(\frac{V_{in}-V_o}{L}\right)(dT_s + d'T_s)$$

$$= \frac{1}{2} \frac{d^2}{Lf_s}\left(\frac{V_{in}-V_o}{V_o}\right) \cdot V_{in}.$$

$$(i_L)_{avg} = i_o.$$

$$\frac{1}{2}\frac{d^2}{Lf_s}\left(\frac{V_{in}-V_o}{V_o}\right) \cdot V_{in} = i_o$$

$$\frac{V_o}{V_{in}^2} = \frac{1}{V_{in} + \frac{2f_sLi_o}{d^2}}$$

$$\boxed{V_o = \frac{V_{in}}{1 + \frac{2f_sLi_o}{d^2 V_{in}}}}$$

Ques 15 $V_{in} = 48\,V$ Buck

$V_o = 12\,V$

$I_o = 10\,A$

$L = 100\,\mu H$

$f_s = 20\,KHz$

$Q = 1.2\,\mu C$

$I_F = 1A$

$V_{GS} = 7.5V$ $I_{sat} = 48\,A$

$V_T = 3.5\,V$

$V_{GS} = 12\,V$ $R_{gs} = 47\,\Omega$

$C_{iss1} = 2000pF$ $C_{iss2} = 1300\,pF$

$C_{rss1} = 600pF$ $C_{rss2} = 200\,pF$

$C_{oss1} = 1200pF$ $C_{oss2} = 400pF$

a) Switching delays in the voltage across the diode?

Soln:- i.e, Time required to transfer the voltage from Switch to diode

$$t_1 = R_g C_{iss2} \ln\left(\frac{V}{V - V_T}\right)$$

$$= 47 \times 1300 \times 10^{-12} \ln\left(\frac{15}{15-3.5}\right)$$

$$\boxed{t_1 = 16.23\,n\,sec.}$$

$$t_2 = R_g C_{iss2} \ln\left(\frac{V - V_T}{V - V_{gscr}}\right)$$

$$= 47 \times 1300 \times 10^{-12} \ln\left(\frac{15-3.5}{15 - V_{gscr}}\right)$$

for V_{gscr}

$$I_o = I_{DS} = I_o, \quad V_{gs} = V_{gscr}$$

$$I_{DS} = \frac{\beta}{2}(V_{GS} - V_T)^2$$

$$48 = \frac{\beta}{2}(7.5 - 3.5)^2$$

$$\boxed{\frac{\beta}{2} = 3}$$

Now, $I_{DS} = I_o$ At $V_{gs} = V_{gscr}$

$$10 = \frac{\beta}{2}(V_{gscr} - V_T)^2$$

$10 = 3(V_{gscr} - 3.5)^2$

$\boxed{V_{gscr} = 5.325}$

Placing in t_2.

$t_2 = 47 \times 1300 \times 10^{-12} \ln\left(\frac{15 - 3.5}{15 - 5.325}\right)$

$\boxed{t_2 = 10.558 \text{ nsec.}}$

$t_3 = \sqrt{2 I_F t_2} - t_2$

$I_F = ?$

$\because Q = I_F \cdot I$

$I_F = \frac{Q}{I} = \frac{1.2\mu}{1} = 1.2 \mu\text{sec}.$

$t_3 = \sqrt{2 \times 1.2\mu \times 10.558 n} - 10.558 n$

$\boxed{t_3 = 148.62 \text{ nsec}}$

$t_4 = R_g C_{iss2} \left(\frac{V_{in} - V_{dscr}}{V - V_{gscr}}\right) = R_g C_{rss2}\left(\frac{V_{in}}{V - V_{gscr}}\right)$

$t_4 = 47 \times 200 \times 10^{-12} \times \frac{.48}{15 - 5.325}$

$\boxed{t_4 = 46.63 \text{ nsec}}$

$\therefore$ Time delay $= t_1 + t_2 + t_3 + t_4$

$= 16.23n + 10.558n + 148.62n + 46.63n$

$\boxed{\text{Time delay} = 222.038 \text{ nsec.}}$

ii) Switching power loss in MOSFET = ?

$P_{sw} = [E_{ON} + E_{OFF}] \times f$

$E_{ON} = V_{in}\left[I_F + \frac{V_{in} - V_{dscr}}{V - V_{gscr}} \frac{R_g C_{rss2}}{2}\right]$

$$E_{ON} = 48\left[1.2\mu + \frac{48-0}{15-5.325} \times \frac{47 \times 200 \times 10^{-12}}{2}\right]$$

$$\boxed{E_{ON} = 58.719\ \mu J}$$

$$E_{OFF} = \frac{1}{2} V_{in}\, I\, (t_2 + t_3)$$

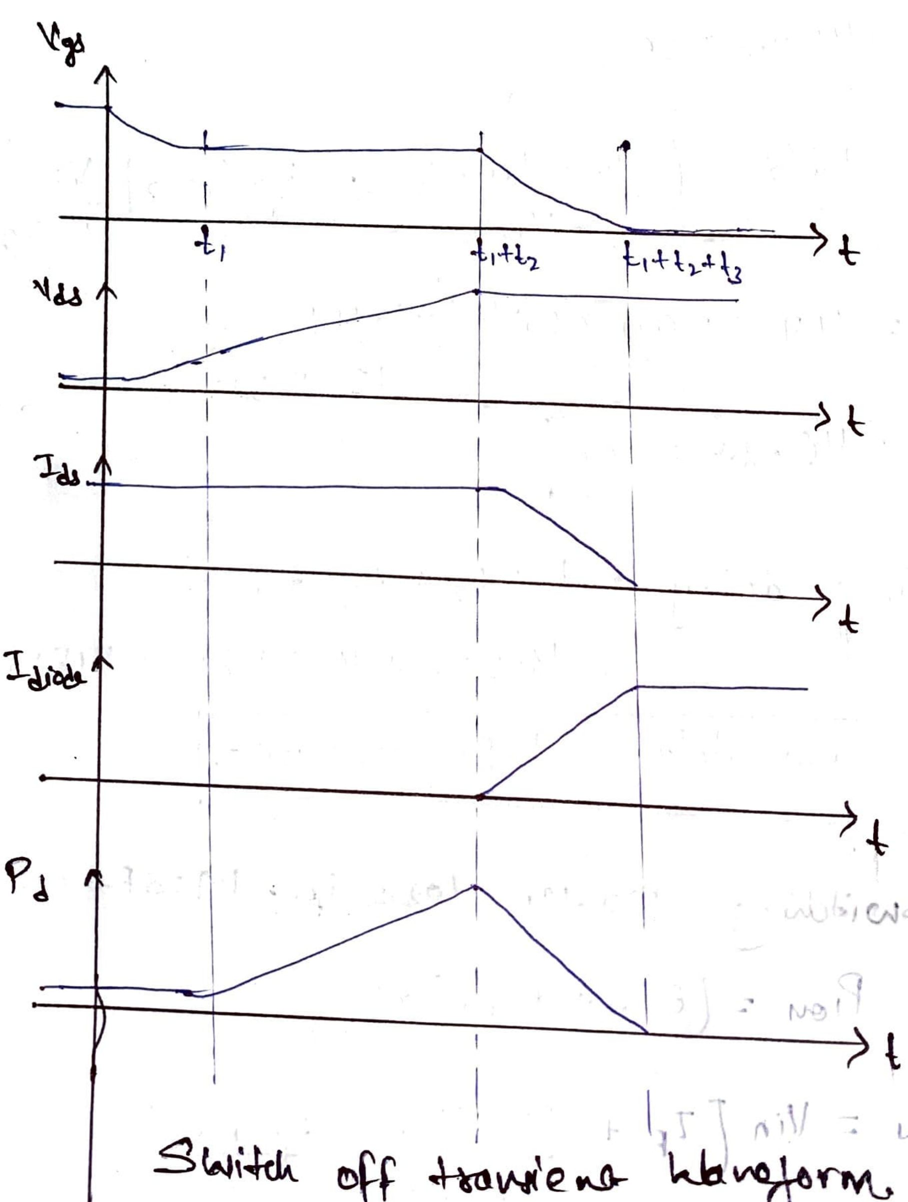
$$= \frac{1}{2} \times 48 \times 10\,[10.558n + 148.62n]$$

$$\boxed{E_{OFF} = 38.13\ \mu J}$$

$$P_{1on} = [E_{ON} + E_{OFF}] \times f$$

$$= [58.719\mu + 38.13\mu] \times 20K$$

$$\boxed{P_{1on} = 1.936\ \text{Watt}}$$

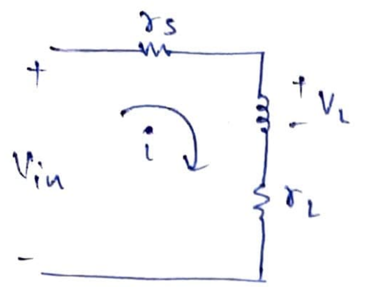


Switch off transient waveform

Ques 16.

a) When SW → ON

$0 < t < DT$

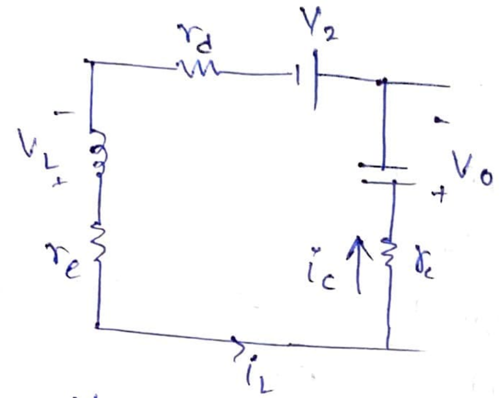


$V_{in} = i_L(r_L + r_S) + V_L$

$A_+ = V_{in} DT - (r_L + r_s) \int_0^{DT} i_L(t) dt$

When SW → OFF

$DT < t < T$



$i_c = i_L - i_o$

$V_L = i_L(r_d + r_L) + V_o + V_c + r_c(i_L - i_o)$

$A_- = (V_o + V_r - I_o r_L)(1-D)T + (r_d + r_L + r_c) \int_{DT}^{T} i_L(t) dt$

$\int_0^{DT} i_L(t) dt = \left(\frac{I_o}{1-D}\right) DT$

$\int_{DT}^{T} i_L(t) = \left(\frac{I_o}{1-D}\right)(1-D)T = I_o T$

$A_+ = A_-$

$V_{in} DT - (r_s + r_L) \frac{I_o}{1-D} \cdot DT = (V_o + V_r - I_o r_L)(1-D)T + (r_L + r_d + r_c) I_o T$

$V_o = V_{in} \frac{D}{1-D} - I_o (r_s + r_L) D - \frac{I_o}{1-D}(r_d + r_c + r_s)$

$+ I_o r_c - V_r$

$$V_o = \frac{12 \times 0.5}{0.5} - \frac{2(0.1+0.3) \times 0.5}{(0.5)^2} - \frac{2}{0.5}(0.3+0.1)$$

$$V_o = 12 - 1.6 - 3 + 0.6 - 0.5$$

$$\boxed{V_o = 7.5\ V}$$

b

After adding switches in parallel there will be a decrease in conduction losses but the switching loss will increase. This will dec the efficiency.

Since all the capacitor will be in parallel and net value of capacitance will inc. and it will inc. the switching time. Hence inorder to improve switching efficiency we can make use of R_g value and we can make use of thick wire to be wound across inductor. Hence resistance values of inductor will be less. Also we can reduce inductance by winding wire closely.

Ques 17 $V_{in} = 48V$ $V_o = 12V$ $L = 225\mu H$ $r_L = 300m\Omega$

$C = 680\mu F$ $ESR = 60m\Omega$ $R_L = 3\Omega$

Stray inductance of sw and diode = 100nH

IRF540 and Diode MUR810

$d = 0.27$

let $f_s = 20kHz$ $V_{DS} = 7.5V$ $V_T = 3.5V$ $V_{dsier} = 1V$

$I_{ds} = 48A$, $R_g = 22\Omega$ $Q = 30nC$

Soln:

$$I + I_R = I\sqrt{\frac{2\tau_F}{t_2}} \rightarrow \text{Under sw} \rightarrow \text{off transient}$$

$$I_o = \frac{V_o}{R} = \frac{12}{3} = 4A$$

$$\boxed{I_o = 4A}$$

$$Q = \tau_F \cdot I$$

$$\tau_F = \frac{Q}{I} = \frac{30 \times 10^{-9}}{4A} = 7.5\,\text{nsec.}$$

$$t_2 = R_g C_{iss2} \ln\left(\frac{V - V_T}{V - V_{gser}}\right)$$

$$C_{iss2} = C_{gd2} + C_{gs2} = 1900 + 150 = 2050\,pF$$

$$t_2 = 22 \times 2050 \times 10^{-12} \ln\left(\frac{15 - 3.5}{15 - 4.65}\right) = 4.77\,\text{nsec.}$$

$$I_{ds} = \frac{\beta}{2}(V_{GS} - V_T)^2$$

$$48 = \beta/2\,(7.5 - 3.5)^2$$

$$\boxed{\beta/2 = 3}$$

$$\therefore I_o = \beta/2\,[V_{GSER} - V_T)^2$$

$$4 = 3\,[V_{GSER} - 3.5)^2$$

$$\boxed{V_{GSER} = 4.65\,V}$$

$$I + I_R = I\sqrt{\frac{2\tau_F}{t_2}}$$

$$I_R = 4\sqrt{\frac{2 \times 7.5 \times 10^{-9}}{4.77 \times 10^{-9}}}$$

$$\boxed{I_R = 3.093\,A}$$

Snubber Circuit Design

$$C_{S1} \approx \frac{R_g I}{V_T} C_{gd} = \frac{22 \times 4}{3.5} \times 150 \times 10^{-12}$$

$$\boxed{C_{S1} = 3.8 \, nF}$$

$$R_{S1} = 2\sqrt{\frac{L_{S1} + L_{S2}}{C_{S1}}} = 2\sqrt{\frac{200 \times 10^{-9}}{3.77 \times 10^{-9}}} = 14.56 \, \Omega$$

$$\boxed{R_{S1} = 14.6 \, \Omega}$$

$$C_{S2} = \left(\frac{L_{S1} + L_{S2}}{V_{in}^2}\right) I_R^2 = \left(\frac{200 \times 10^{-9}}{(48)^2}\right) \times (3.0932)^2$$

$$\boxed{C_{S2} = 830.5 \, pF}$$

$$R_{S2} = 1.2\sqrt{\frac{L_{S1} + L_{S2}}{C_{S2}}} = 1.2\sqrt{\frac{200 \times 10^{-9}}{830.5 \times 10^{-12}}}$$

$$\boxed{R_{S2} = 18.62 \, \Omega}$$

Hence By simulation,

Power dissipation in snubber Resistance,

$$\boxed{P_{RS1} = 132.642 \, MW}$$

$$\boxed{P_{RS2} = 33.164 \, MW}$$