13/09/19 D.C - D.C Converters

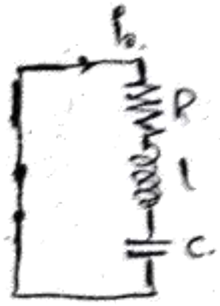
UNIT-IV

internal $0 < t < t_1 \, (=kT)$

at the End of this mode the load Current becomes.

$$i_1 (t_0 = t_1 = kT) = I_2 .$$

mode II $\quad t_1 < t < t_2 .$



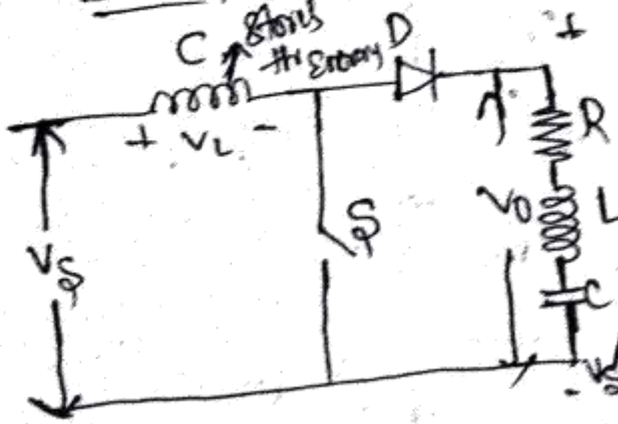
With initial Current $i_2 (t=0) = I_2 .$

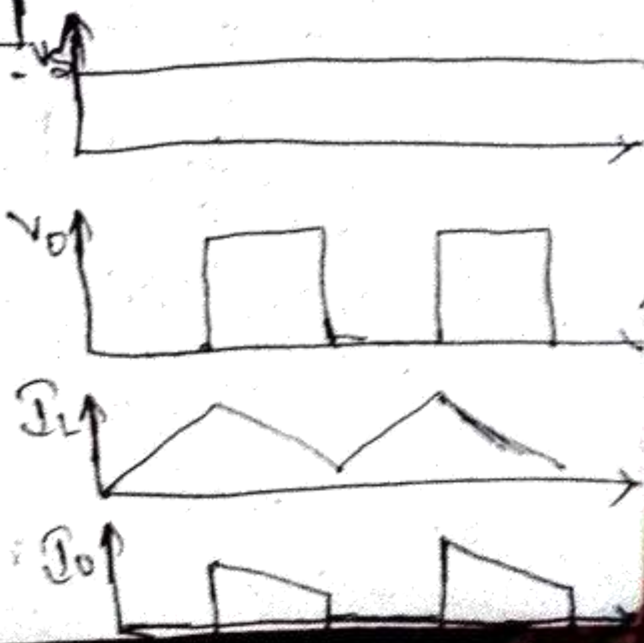
$$i_2 (t) = I_2 . e^{-t/Rc} - E/R \left(1 - e^{-tR/c}\right).$$

[chopper is not regulated o/p voltage].

16/09/19

Step up Chopper:-





Energy Stored in inductor during on time

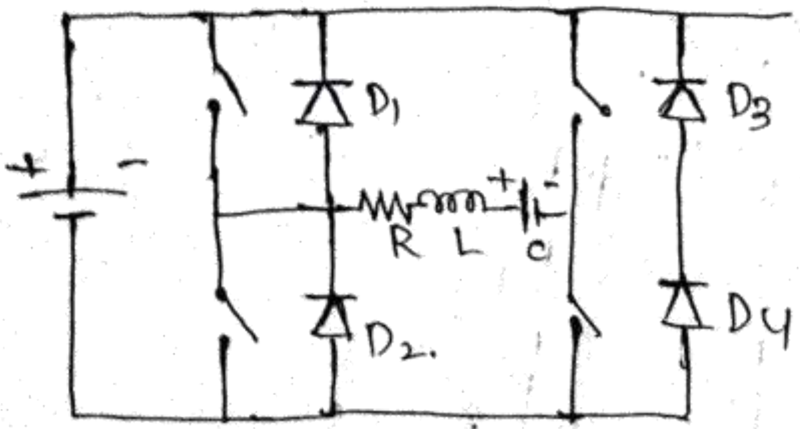
$$E_L = \frac{(\Delta I)}{2} \cdot t_1 .$$

E_L = (Average voltage across inductor) - (Average

$$E_L = V_S \left(\frac{I_1 + I_2}{2} \right) t_1$$

$$E_L = (V_S - V_0) \left(\frac{I_2 + I_1}{2} \right) t_2 .$$

* Four Quadrant operator Chopper (or) multi Quadrant operator Chopper:-



V_0

② S_2 - modulated (or) operated. D_1, D_4 Conduct. $V_0, -I_0$

① $+V_0, +I_0$. S_1 - modulate (or) operate. S_4 - kept on. S_3, S_4 - No-operation. D_2 Conduct.

I_0.

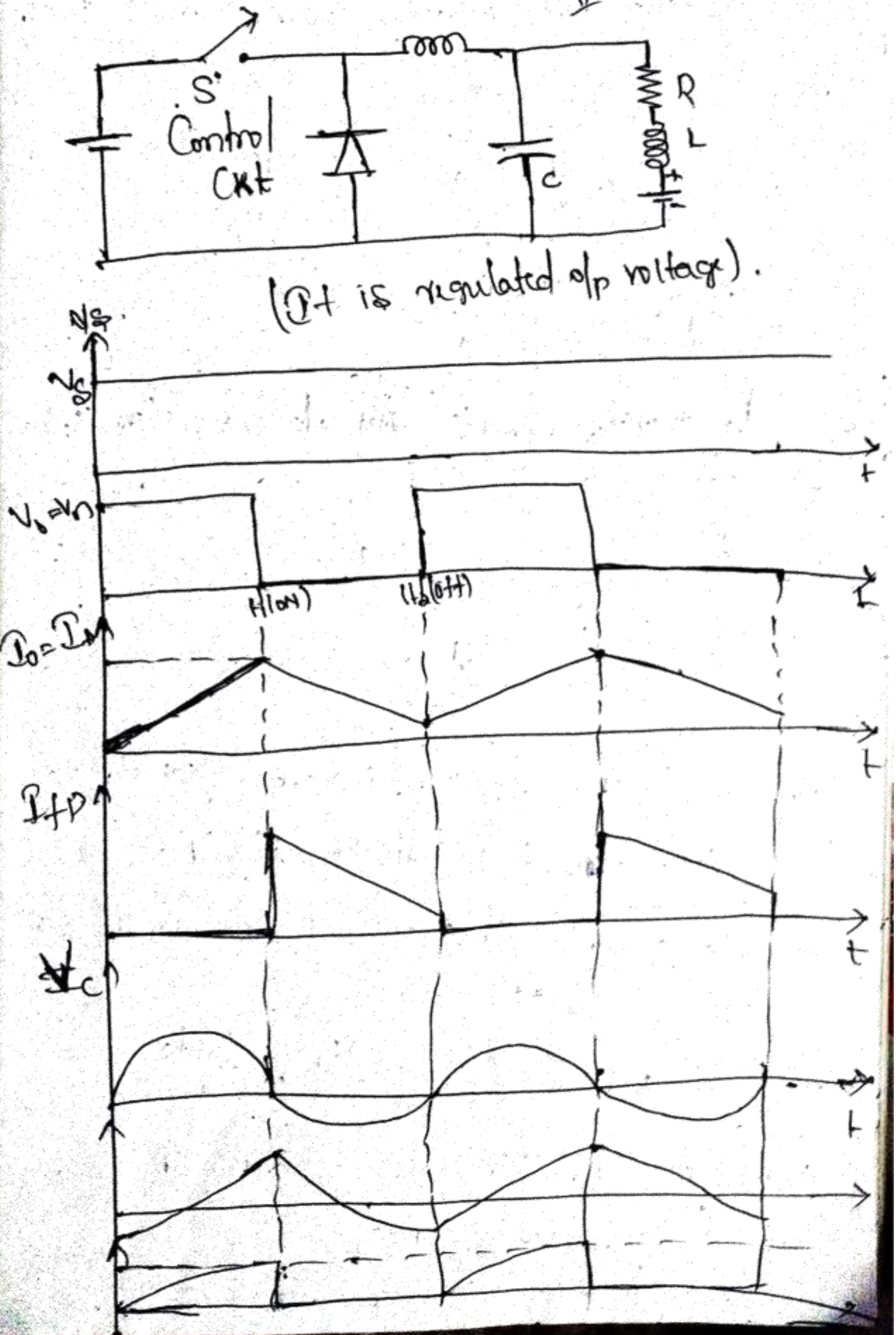
③ S_3 - modulated. S_2 - Always kept on. $-V_0, -I_0$

④ S_4 - modulated. D_3, D_2 Conduct. $-V_0, I_0$

* SMPS [Switch Mode power Supply]

(i) Buck Converters :-

I mode → $0 \le t \le t_1$
II mode → $t_1 \le t \le t_2$



Voltage across inductor L_1.

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

Assuming that the inductor Current rises linearly from i_1 to i_2 in time t_1.

$$V_s - V_0 = \frac{I_2 - I_1}{t_1} = L.\frac{\Delta I}{t_1} \longrightarrow (1)$$

$$t_1 = \frac{\Delta I . L}{V_s - V_a} \longrightarrow (2)$$

And the inductor Currents falls linearly from i_2 to i_1 in time t_2.

$$-V_0 = -L.\frac{\Delta I}{t_2} \longrightarrow (3)$$

$$t_2 = \frac{\Delta I L}{V_0} \longrightarrow (4)$$

Where, $\Delta I = I_2 - I_1$ is the peak to peak ripple Current of the inductor "L"

→ Equating the values of ΔI in Eqn (1) & (3) gives

$$\Delta I = \frac{(V_s - V_a)t_1}{L} = \frac{V_a t_2}{L}$$

Substitute $t_1 = kT$ and $t_2 = (1-k)T$

the Average o/p voltage is

$$\boxed{V_a = V_s . t_1 / T = k . V_s} \longrightarrow (5)$$

Assuming a lossless Circuit

$$V_s I_s = V_a I_a = k V_s I_a.$$

and average i/p Current is

$$\boxed{I_s = k \cdot I_a} \longrightarrow (6)$$

The Switching period 'T' Can be Expressed as

$$T = 1/f = t_1 t_2 = \frac{\Delta I_L}{V_s - V_a} + \frac{\Delta I_L}{V_a}$$

$$\boxed{T = 1/f = \frac{\Delta I L V_s}{V_a (V_s - V_a)}} \longrightarrow (7)$$

Which gives the peak to peak ripple Current.

$$\Delta I = \frac{V_a (V_s - V_a)}{f L V_s} \longrightarrow (8)$$

(or)

$$\Delta I = \frac{V_s k (1-k)}{f_L} \longrightarrow (9)$$

using kirchoff's Current load, Inductor. Current I_L is.

$$I_L = i_c + i_0$$

If we assume the Load ripple fraction current Δi_0 is very small and negligible $\Delta i_L = \Delta I_c$

→ The Average Capacitor Current which flows into for $t_1/2 + t_2/2 = T/2$.

$$I_c = \frac{\Delta I}{4}$$

The Capacitor voltage is Expressed as

$$v_c = \frac{1}{C}\int i_c\,dt + v_c(t=0)$$

and the peak to peak ripple voltage of the Capacitor is

$$\Delta V_c = V_c - V_c(t=0) = \frac{1}{C}\int_0^{T/2} \frac{\Delta I}{4}\,dt.$$

$$= \frac{\Delta I T}{8C} = \frac{\Delta I}{8fC} \longrightarrow (10)$$

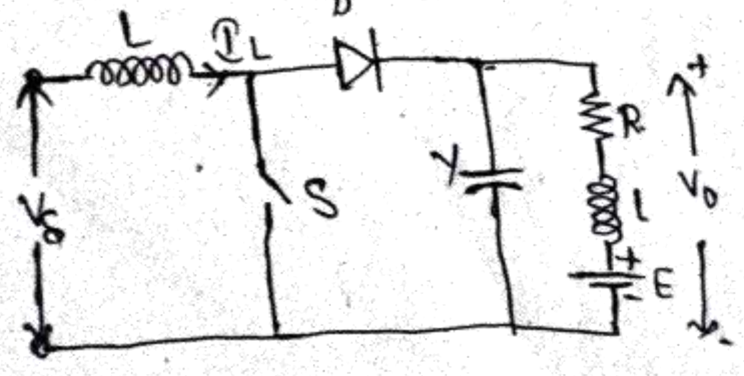
Substituting the values of ΔI from Eq (8), (9) & (10).

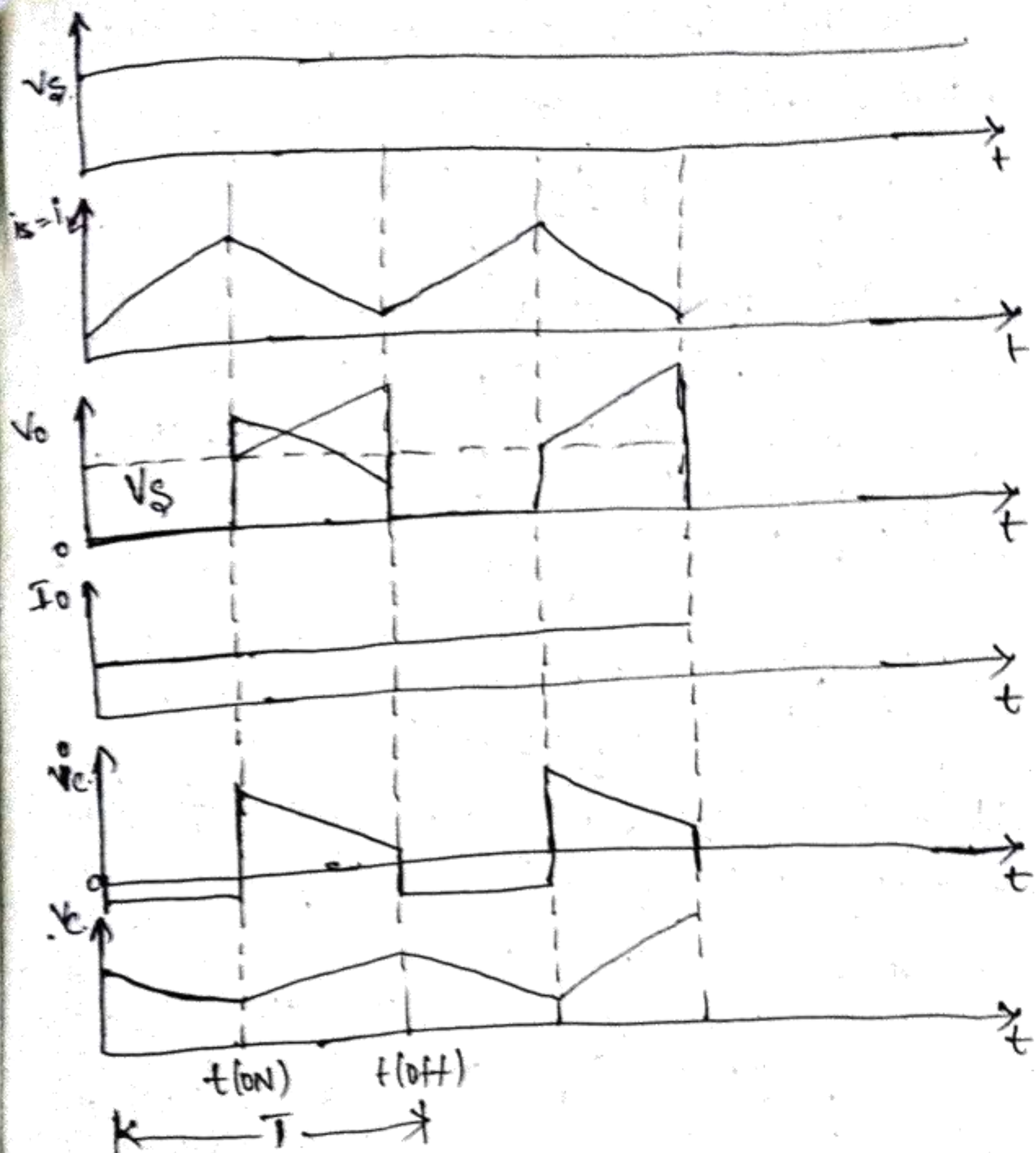
$$\Delta V_c = \frac{V_a(V_s - V_a)}{8LCf^2 V_s} \longrightarrow (11)$$

$$\Delta V_c = \frac{V_s k(1-k)}{8LCf^2} \longrightarrow (12).$$

17/09/19

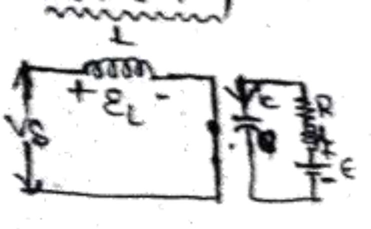
Boost Converter :- $(V_0 > V_S)$.





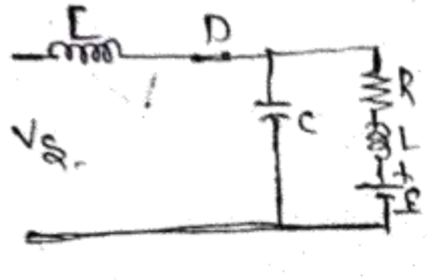
Switch ON

$0 < t < t_1$



Switch OFF

$t_1 < t < t_2$



$$\boxed{K = t/T}$$

$$\therefore \boxed{k = \frac{1}{1-k}}$$

Assume that the inductor current rises linearly from I_1 to I_2 in time t_1

$$\boxed{V_s = L\frac{I_2 - I_1}{t_1}} = L\frac{\Delta I}{t_1} \rightarrow (1)$$

(or) $$\boxed{t_1 = \frac{\Delta I\, L}{V_s}} \rightarrow (2)$$

And the inductor current falls linearly from I_2 to I_1 in time "t_2".

$$\boxed{V_s - V_a = -L\frac{\Delta I}{t_2}} \text{ — } (3)$$

(or) $$\boxed{t_2 = \frac{\Delta I L}{V_a - V_s}} \text{ — } (4)$$

Where, $\Delta I = I_2 - I_1$ is the peak to peak ripple current of inductor "L"

→ from Eqn (1) & (3)

$$\Delta I = \frac{V_s t_1}{L} = \frac{(V_a - V_s)t_2}{L}$$

Substituting $t_1 = kT$ and $t_2 = (1-k)T$ yield the average o/p voltage.

$$\boxed{V_a = V_s\, T/t_1 = V_s(1-k)} \rightarrow (5)$$

Which gives $\boxed{(1-k) = V_a/V_s} \rightarrow (6)$

→ Substituting $k = t_1/T = t_1 f$ into Eqn (6)

$$\boxed{t_1 = \frac{V_a - V_s}{V_a \cdot f}} \rightarrow (7)$$

Assume lossless Current, $V_s I_s = V_a I_a = \frac{V_s I_a}{1-k}$

the average i/p Current is,

$$I_s = \frac{I_a}{1-k} \longrightarrow (8)$$

The Switching Period 'T' Can be found.

$$T = 1/f = t_1 + t_2 = \frac{\Delta I_L}{V_s} + \frac{\Delta I L}{V_a - V_s}$$

$$T = \frac{\Delta I L V_a}{V_s (V_a - V_s)} \longrightarrow (9)$$

and thus gives the peak to peak ripple Current

$$\Delta I = \frac{V_s (V_a - V_s)}{f . L . V_a} \longrightarrow (10)$$

$$\Delta I = \frac{V_s}{f} . k/L \longrightarrow (11)$$

When the transistor is ON, the Capacitor Supplies the load Current for $t = t_1$.

→ The average Capacitor Current during time "t_1" is $I_c = I_a$. and the peak to peak ripple voltage of the Capacitor is.

Changing Capacitor voltage.

$$\Delta V_c = V_c - V_c (t_{=0}) = 1/c \int_0^{t_1} I_c dt = 1/c \int_0^{t_1} I_a dt = \frac{I_a t_1}{c}$$

Substituting $t_1 = \frac{(V_a - V_s)}{V_a f}$ from Eqn (7) gives

$$\Delta V_c = \frac{I_a (V_a - V_s)}{V_a f C} \longrightarrow (13)$$

(or)

$$\Delta V_c = \frac{I_a K}{f C} \longrightarrow (14)$$

Condition for Continuos Inductor Current & Capacitor voltage.

If I_L is Average inductor Current, the inductor ripple Current

$$\Delta I = 2 I_L.$$

using Eqn (5) & (11) We get.

$$\frac{K V_s}{f L} = 2 I_L = 2 I_a = \frac{2 V_s}{(1-K) R}.$$

Which gives the Critical value of inductor L_c is

$$L_c = L = \frac{K(1-K)R}{2f} \longrightarrow (15)$$

If V_c is Average Capacitor voltage, the Capacitor ripple voltage $\Delta V_c = 2V_a$. using Eqn (14)

$$\frac{I_a K}{C f} = 2 V_a = 2 I_a R.$$

Which gives Critical value of Capacitor.

$$\boxed{C_c = \frac{K}{2fR}} \longrightarrow (16)$$

For Buck Converter:-

⇒ Condition for Continuous inductor Current & Capacitor voltage.

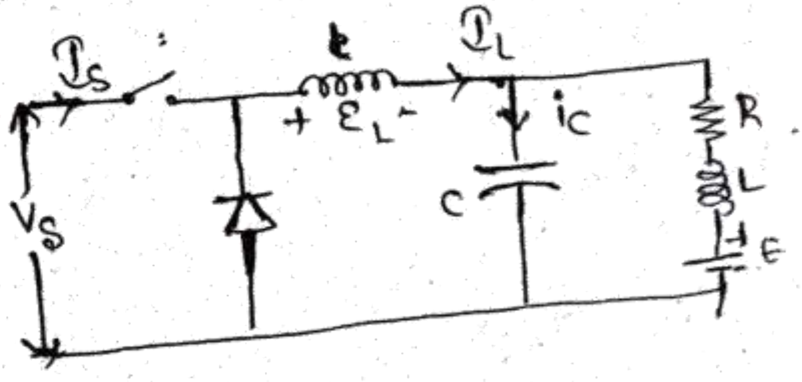
$$L_c = L = \text{Critical value of Inductor} = \frac{(1-K)R}{2f}$$

Critical value of Capacitor $C_c = C = \frac{1-K}{16LF^2}$.

Problem :-

1. The Buck Regulator shown in figure has an i/p voltage of $V_S = 12V$. the required average o/p voltage is $V_a = 5V$, at $R = 500\Omega$ and the Peak to peak o/p ripple voltage is ~~volt~~ "20 mV". The switching frequency is 25 KHZ. If the Peak to peak ripple Current of the inductor is limited to 0.8 A., Determine the duty cycle (K), the filter inductance (L). (C) the filter Capacitor (C) (d) the Critical values of L and C.

Sol:-



Given data,

$V_s = 12V$, $\Delta V_c = 20mV$, $\Delta I = 0.8A$,

$f = 25KHz$

$V_a = 5V$

$R = 500\Omega$.

(a) $V_a = K \cdot V_s$

$K = V_a / V_s = 5/12 = 4.16\%$.

(b) peak to peak ripple Current.

$$\Delta I = \frac{V_a(V_s - V_a)}{f \cdot L \cdot V_s} = \frac{5(12-5)}{25 \times 10^3 \cdot L \cdot 12}$$

$$L = \frac{0.8 \times 25 \times 12}{5 \times 7}$$

$= 145.83 \mu H$

(c) Peak to peak Ripple voltage of Capacitor

$$\Delta V_c = \frac{\Delta I}{8 \cdot f \cdot c}$$

$$C = \frac{\Delta I}{8 \cdot f \cdot \Delta V_c} = \frac{0.8}{8 \times 25 \times 10^3 \times 20 \times 10^{-3}}$$

$= 200 \mu F$

(d) $L_c = \frac{(1-K)R}{2f}$

$$L_c = \frac{(1 - 0.416) \times 500}{2 \times 25 \times 10^3} = 5.83 mH.$$

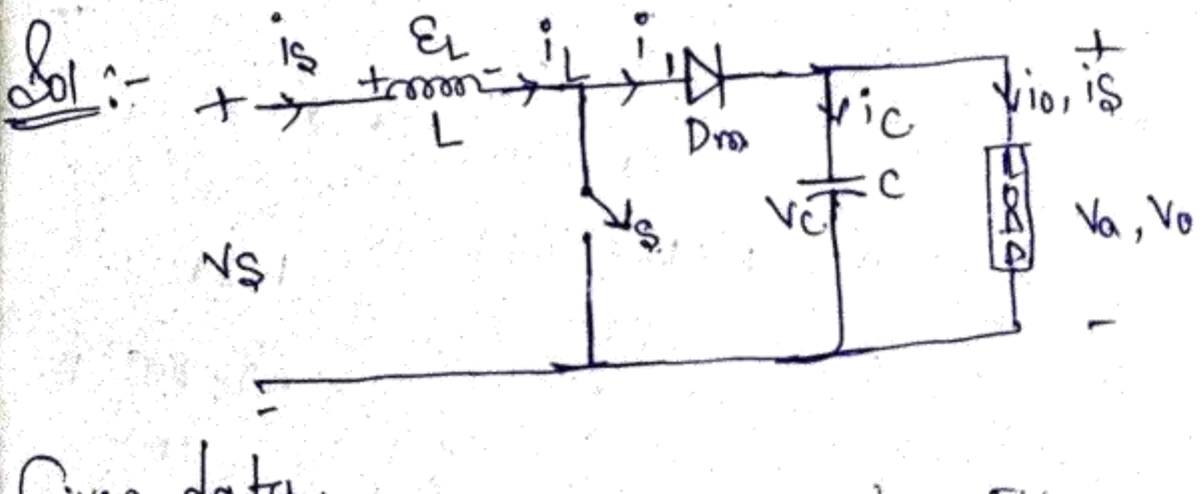
$$C_c = \frac{1-K}{16LF^2} = \frac{1-41.6}{16 \times 145 \times 25}$$

$$= 4.02 \times 10^{-7} \mu F.$$

12/09/19

1. A Boost Regular Shown in fig an input voltage of $V_s = 5V$. The avg o/p voltage $V_a = 15V$ and the avg load Current $I_o =$ 0.5A, The switching frequency is 25 KHZ. If L is 150 μH and C = 220 μF. Determine (a) Duty cycle, K (b) Ripple Current of inductor, ΔI (c) The peak Current of Inductor I_2 (d) The ripple voltage of filter Capacitor ΔV_c and (5) Critical values of L & C.

Sol :-



Given data,

$V_a = 15V$, $I_o = 0.5A$, $f = 25KHZ$, $V_s = 5V$

$L = 150 \times 10^{-6} H$, $C = 220 \times 10^{-6} F$.

(a) $V_a = V_S \frac{1}{1-K}$.

$15 = 5/_{1-K} \Rightarrow K = 2/3 = 0.667$ (or) 66.7%

(b) $\Delta I = \frac{V_s(V_a - V_s)}{f \cdot L \cdot V_a} = \frac{5(15-15)}{25 \times 10^3 \times 150 \times 10^{-6} \times 15} \approx 0.89 A$

(c) $I_S = \frac{I_a}{1-K} = \frac{0.5}{1-0.6667} = 1.5A$ Peak inductor current

$I_2 = I_S + \frac{\Delta I}{2} = 1.5 + \frac{0.89}{2}$

$= 1.945A.$

(d) $\Delta V_c = \frac{I_a K}{f.C} = \frac{0.5 \times 0.6667}{25000 \times 220 \times 10^{-6}}$

$= 60.61 mV.$

(e) $L_c = \frac{K(1-K).R}{2f}$

$R = V_a / I_a = \frac{15}{0.5} = 30$

$= \frac{0.667(1-0.667).30}{2 \times 25000} = 1.33 \times 10^{-4}$

$= 0.0001 H.$

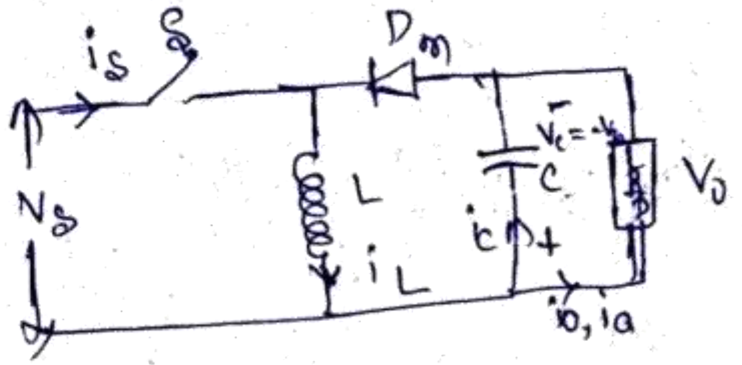
(or)

$= 133 \mu H.$

(f) $C_c = \frac{k}{2fR} = \frac{0.667}{2 \times 25000 \times 30}$

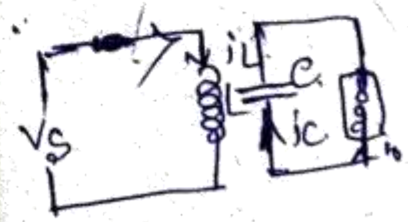
$= 0.44 \mu F$

Buck - Boost Converter :-



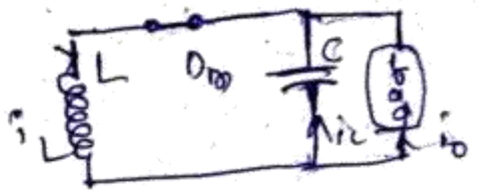
Mode - I

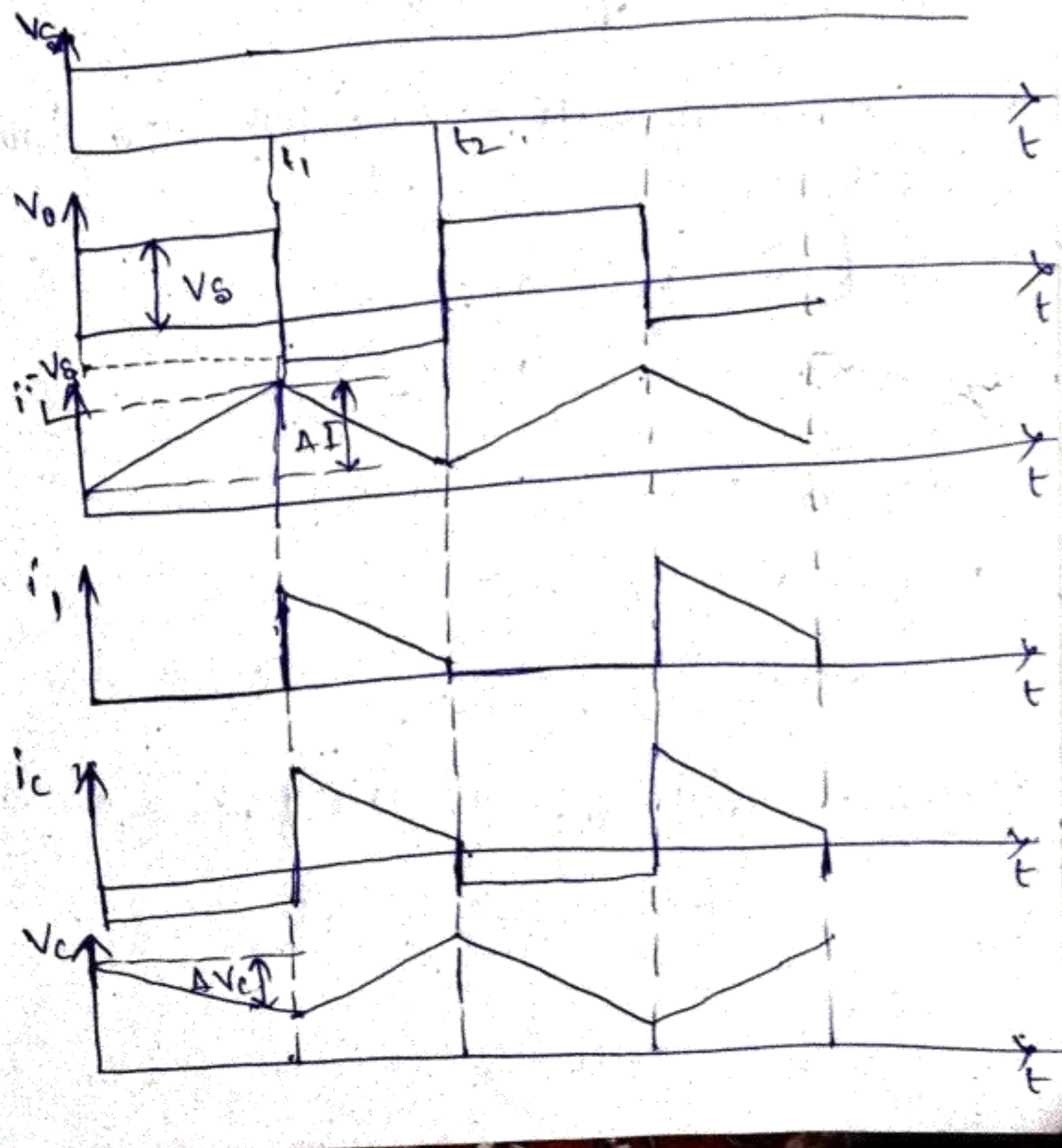
$0 \le t \le t_1$



Mode - II

$t_1 \le t \le t_2$





19/09/19

Assuming that the inductor current rises linearly from I_1 to I_2 in time t_1.

$$V_s = L.\frac{I_2 - I_1}{t_1} = L\frac{\Delta I}{t_1} \rightarrow 1$$

(or)

$$t_1 = \frac{\Delta I_L}{V_s} \rightarrow 2$$

and the inductor current falls linearly from I_2 to I_1 in time t_2.

$$V_a = -L\frac{\Delta I}{t_2} \rightarrow 3$$

(or)

$$t_2 = \frac{-\Delta I L}{V_a} \rightarrow 4$$

Where $\Delta I = I_2 - I_1$ is the peak to peak ripple current of inductor 'L'

from Eqn 1 and 3

$$\Delta I = \frac{V_s t_1}{L} = \frac{-V_a t_2}{L}.$$

Substituting $t_1 = kT$ & $t_2 = (1-k)T$.

The average o/p voltage is,

$$\boxed{V_a = -\frac{V_s k}{1-k}} \rightarrow 5$$

Substituting $t_1 = kT$ and $t_2 = (1-k)T$ into Eq 5 yields

$$(1-k) = \frac{-V_s}{V_a - V_s} \rightarrow 6$$

Substituting $t_2 = (1-k)T$ and $(1-k)$ from Eq 6 in Eq 5 yields

$$t_1 = \frac{V_a}{(V_a - V_s) f} \longrightarrow (7)$$

Assume loss less Circuit, $V_s I_s = V_a I_a = \frac{V_s I_a}{1-k} K$. and the average i/p Current I_s is related to the average o/p Current I_a by.

$$I_s = \frac{I_a K}{1-k} \longrightarrow (8)$$

The Switching period "T" Can be found from

$$T = 1/f = t_1 + t_2 = \frac{\Delta I_L}{V_s} + \frac{\Delta I_L}{V_a} = \frac{\Delta I L (V_a - V_s)}{V_s V_a} \longrightarrow (9)$$

The peak to peak ripple Current from Eqn (9)

$$\Delta I = \frac{V_s . V_a}{f L (V_a - V_s)} \longrightarrow (10)$$

$$(or) \quad \Delta I = \frac{V_s K}{f L}.$$

When Switch is on, the filter Capacitor supplies the load current for $t = t_1$. The average discharging Current of Capacitor is $I_c = I_a$ and the peak-to peak ripple voltage of Capacitor is.

$$\Delta V_c = 1/C \int I_c dt = 1/C \int I_a dt = \frac{I_a t_1}{C} \longrightarrow (12)$$

Substituting $t_1 = \frac{V_a}{(V_a - V_s).f}$ from Eqn (7) becomes

$$\Delta V_c = \frac{I_a . V_a}{(V_a - V_s).f.C} \longrightarrow (13)$$

(or)

$$\Delta V_c = \frac{I_a K}{f.C} \longrightarrow (14)$$

Condition for Continuous inductor Current and Capacitor voltage is

If I_L is the average inductor Current, Inductor ripple Current $\Delta I = 2I_L$ using Eqn (5) and Eqn (11), we get.

$$\frac{K \cdot V_s}{fL} = 2I_L = 2I_a = \frac{2KV_s}{(1-K)R}.$$

Which gives the Critical value of inductor L_c

$$L_c = L = \frac{(1-K)R}{2f} \longrightarrow (15)$$

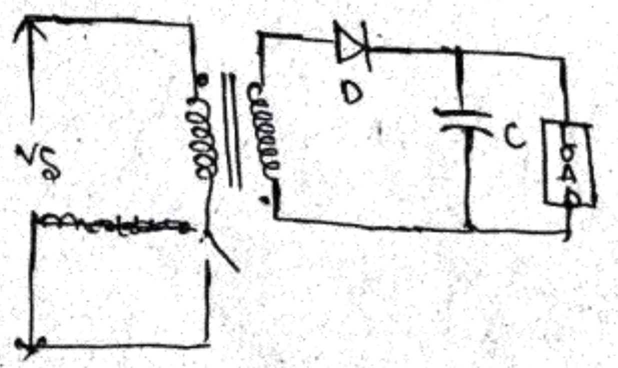
If V_c is the average, the Capacitor ripple voltage $\Delta V_c = 2V_a$ using Eqn (14) we get.

$$\frac{I_a K}{Cf} = 2V_a = 2I_a R.$$

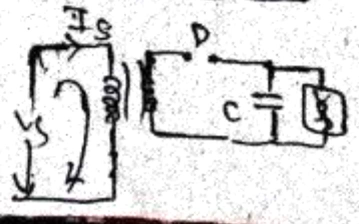
Which gives the Critical value of Capacitor C_c is.

$$C_c = C = K/2fR \longrightarrow (16)$$

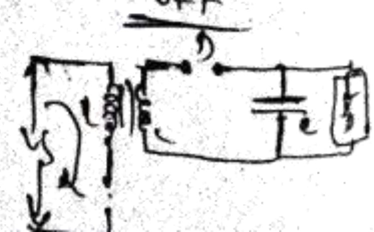
* Fly Back Converter (or) forward back :- IMP



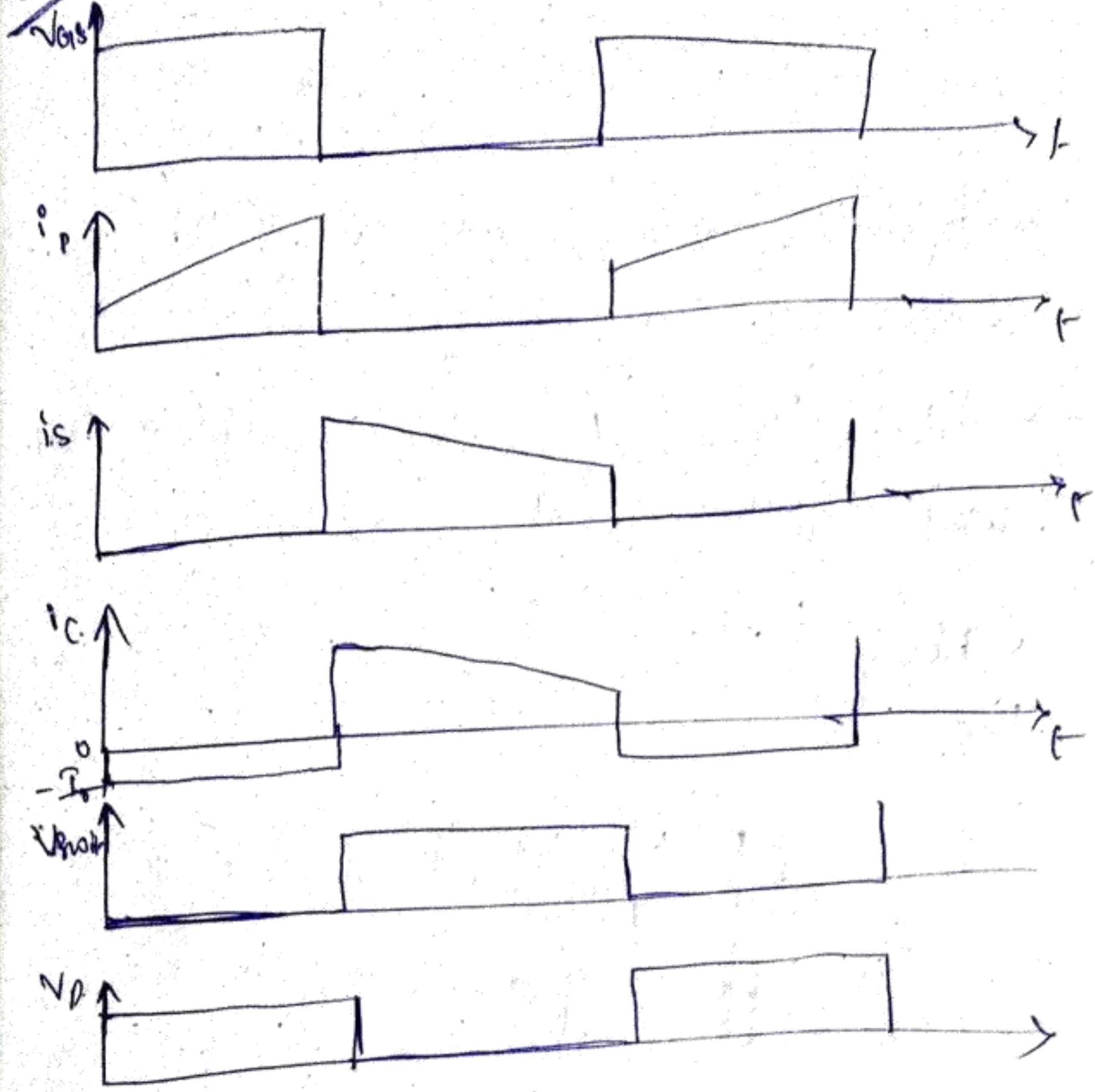
Mode-I ON



OFF



21/09/19



$$V_0 = \frac{K}{1-K} V_S \rightarrow \text{Buck Boost}$$

$$V_0 = \frac{N_2}{N_1} \cdot \frac{K}{1-K} V_S \Rightarrow \text{Fly back Converter.}$$

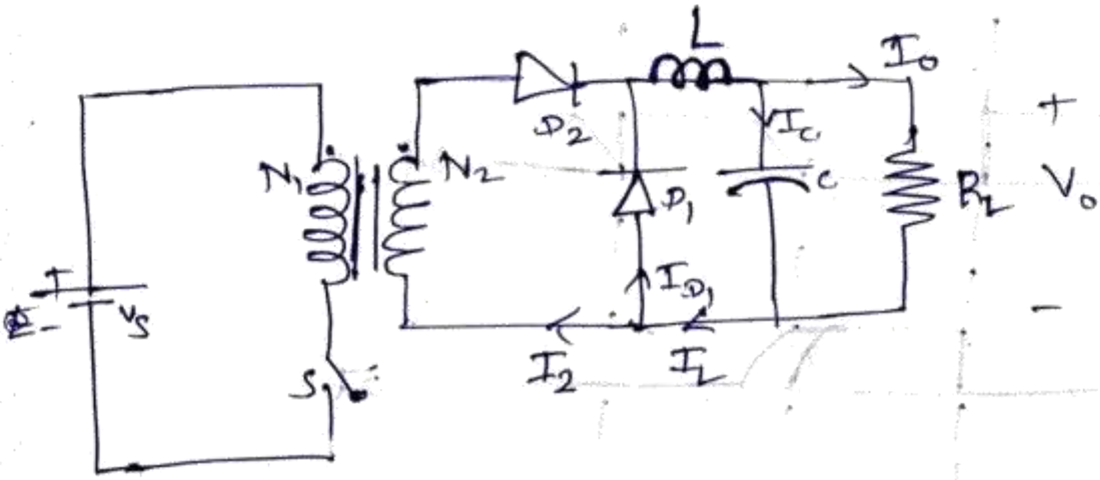
$$V_o = \frac{K}{1-K} V_s \rightarrow \text{Buck Boost}$$

$$V_o = \frac{N_2}{N_1} \frac{K}{1-K} V_s \rightarrow \text{fly back converter}$$

→ Buck Boost converter & fly back converter is only one differences.
— $\boxed{\text{isolations}}$

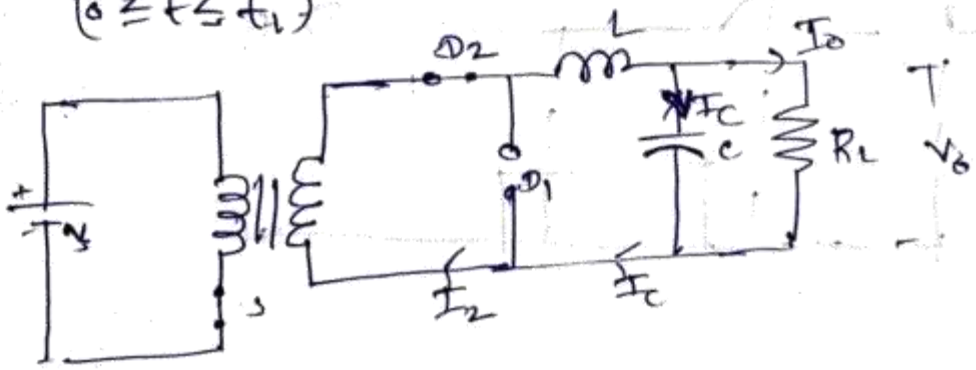
* Forward Converter :-

→ Forward converter is derived from Buck converter



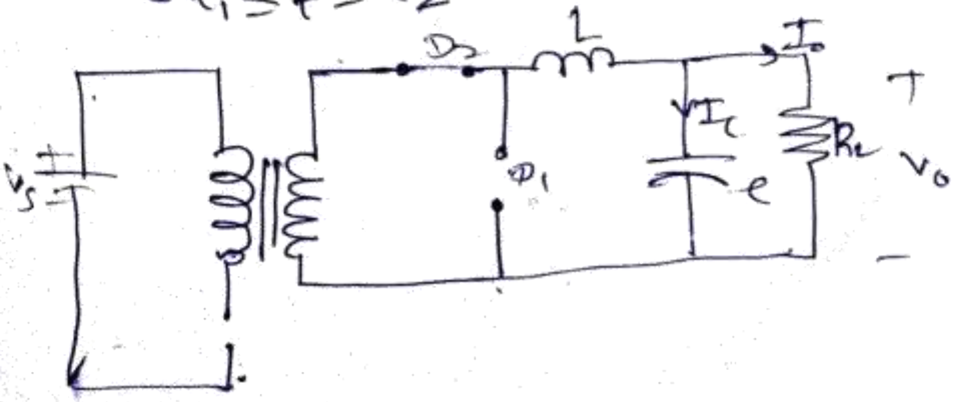
Switch ON

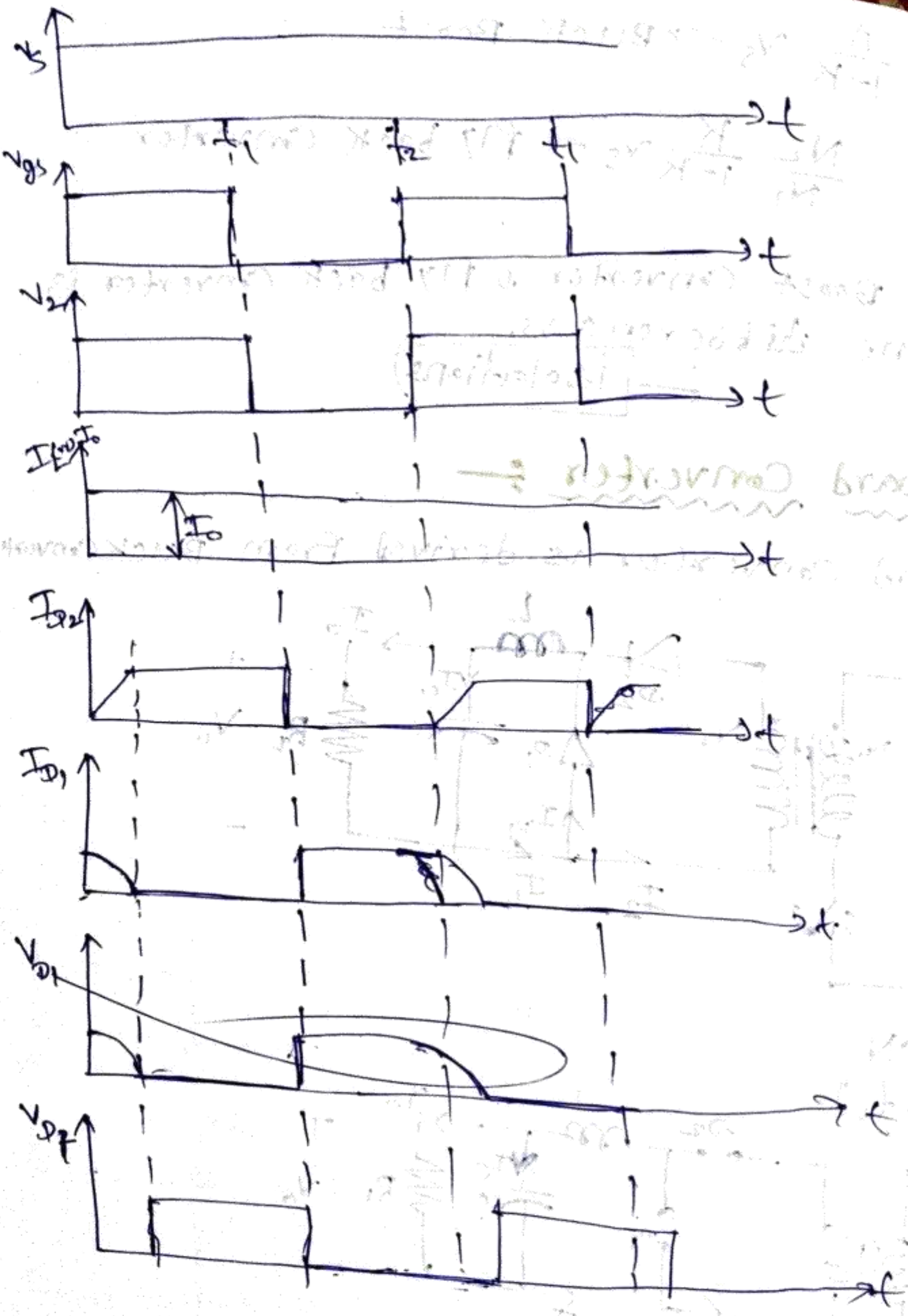
$(0 \leq t \leq t_1)$



switch off :-

$t_1 \leq t \leq t_2$





Vs
t
t1
t2
t1
Vgs
V2
Io
ID2
ID1
VD1
VD2