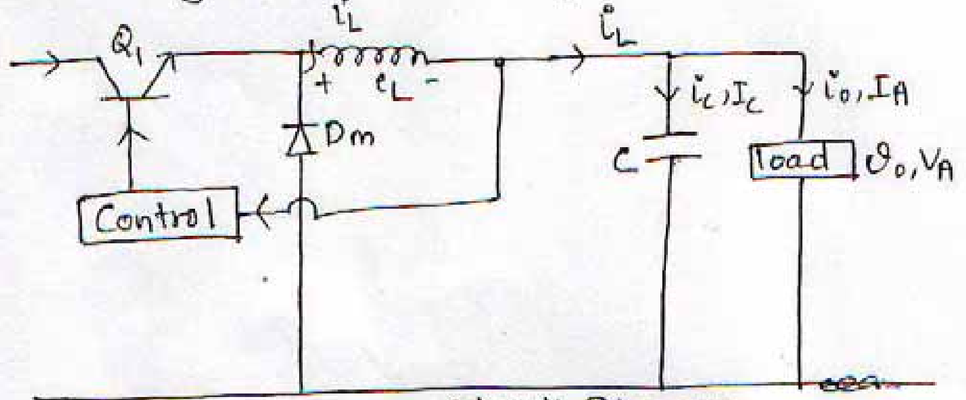
i) Buck Converter (regulator)
ii) Boost " (regulator)
iii) Buck-Boost Converter (regulator)

Buck Converter

→ Average output voltage V_a is less than the input voltage V_s.



Circuit Diagram

→ Similar to a step down converter

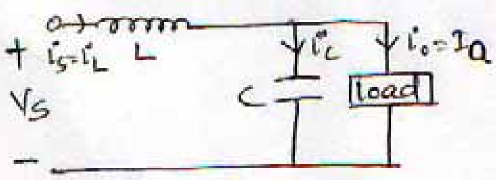
Mode-1

→ At $t=0$, Q_1 is switched on
→ The i/p current which rises flows through L, c and the load.

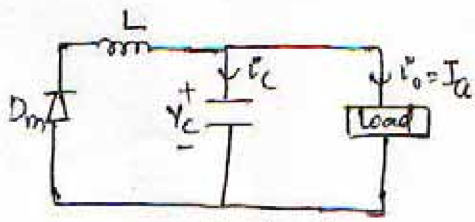
Mode-2

→ At $t=t_1$, Q_1 is switched off
→ Freewheeling diode D_m conducts due to energy stored in the inductor, and the inductor current continues to flow through L, c, load and diode D_m.
→ The inductor falls until Q_1 is switched on again in the next cycle.

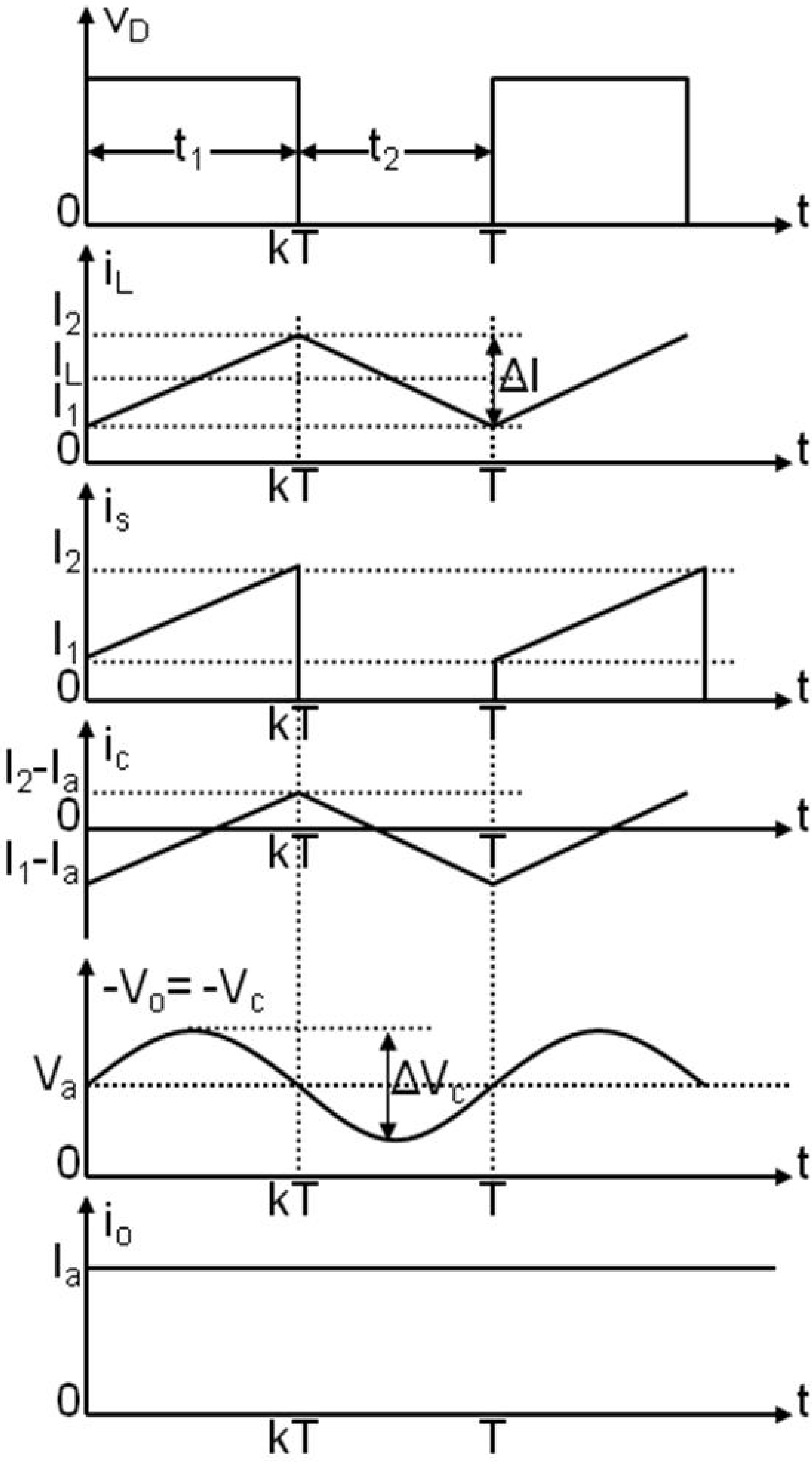
EQUIVALENT CIRCUITS:-



Mode-1



Mode-2



v_D
t_1
t_2
0
t
kT
T
i_L
I_2
I_L
I_1
ΔI
i_s
i_c
I_2-I_a
I_1-I_a
$-V_o$= $-V_c$
V_a
ΔV_c
i_o
I_a

Derivations:-

Mode 1 $\quad e_L = L\frac{di_L}{dt}\ ,\quad e_L = V_S - V_a$ —— (i)

$$e_L dt = L di_L$$

$$\int_0^{t_1} e_L dt = \int_{I_1}^{I_2} L di_L$$

$$e_L t_1 = L(I_2 - I_1)$$

$$t_1 = \frac{L(I_2 - I_1)}{e_L} = \frac{L\Delta I}{V_S - V_a} \text{ —— (ii)}$$

Mode-2

$$e_L + V_a = 0$$

$$L\frac{di_L}{dt} = -V_a$$

$$L di_L = -V_a dt$$

Integrating,

$$L\int_{I_2}^{I_1} di_L = -V_a\int_0^{t_2} dt$$

$$L(I_1 - I_2) = -V_a t_2$$

$$t_2 = \frac{L(I_1 - I_2)}{-V_a} = \frac{L(I_2 - I_1)}{V_a} \text{ —— (iii)}$$

Further, $\quad I_2 - I_1 = \Delta I$

so, $\quad t_2 = \frac{L\Delta I}{V_a}$ —— (IV)

Equating ΔI from eqn (ii) and (IV), we get;

$$\frac{(V_S - V_a)t_1}{L} = \frac{V_a}{L}.t_2$$

$t_1 = Kt$ and $t_2 = (1-K)t$ where K = duty cycle

$$\frac{(V_S - V_a)K\cancel{t}}{\cancel{L}} = \frac{V_a}{\cancel{L}}.(1-K)\cancel{t}$$

$$KV_S - KV_a = V_a - KV_a$$

$$\therefore V_a = KV_S \text{ —— (V)}$$

Transfer function of Buck Converter $= \frac{V_a}{V_S} = K$

Assuming a lossless circuit,

$$V_S I_S = V_a I_a = K V_S I_a$$

$$\text{or, } V_S I_S = K V_S I_a$$

$$I_S = K I_a \quad \text{———— (VI)}$$

The switching period T can be expressed as,

$$T = 1/f = t_1 + t_2$$

$$= \frac{\Delta I L}{V_S - V_a} + \frac{\Delta I L}{V_a} \quad [\text{from eq}^n \text{ iii a (IV)}]$$

$$= \frac{\Delta I L V_S}{V_a (V_S - V_a)}$$

Which gives peak to peak ripple current as,

$$\Delta I = \frac{V_a (V_S - V_a)}{L V_S} . T$$

$$= \frac{V_a (V_S - V_a)}{f L V_S}$$

$$= \frac{V_a (V_S - K V_S)}{f L V_S}$$

$$= \frac{K \cancel{V_S} (V_S - K V_S)}{f L \cancel{V_S}}$$

$$= \frac{K V_S - K^2 V_S}{f L}$$

$$= \frac{K V_S (1-K)}{f L}$$

$$\therefore \Delta I = \frac{V_S K (1-K)}{f L} \quad \text{———— (VII)}$$

Using KCL, $i_L = i_c + i_o$

If we assume load ripple current Δi_o is very small, then.

$\Delta i_L \simeq \Delta i_c$. The average capacitor current which flows into for $\frac{t_1}{2} + \frac{t_1}{2} = T/2$ will be,

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

The capacitor voltage will be,

$$V_c = \frac{1}{C}\int i\,dt + V_c\Big|_{t=0}$$

and the peak to peak ripple voltage of the capacitor is,

$$\Delta V_c = \hat{v}_c - V_c(t=0)$$

$$= \frac{1}{C}\int_0^{T/2}\left(\frac{\Delta I}{4}\right)dt$$

$$= \frac{1}{C}\cdot\frac{\Delta I}{4}\cdot T/2$$

$$\therefore \Delta V_c = \frac{\Delta I}{8fC}$$

Substituting the value of ΔI, we get,

$$\Delta V_c = \frac{KV_S(1-K)}{8LCf^2}$$

$$\therefore \boxed{\Delta V_c = \frac{V_a(1-K)}{8LCf^2}}$$

<u>Condition for Continuous inductor current and Capacitor Voltage</u>

If I_L is the average inductor current, the inductor ripple current $\Delta I = 2I_L$.

Further, $\Delta I = \frac{V_S K(1-K)}{fL}$

$$2I_L = \frac{V_S K(1-K)}{fL}$$

$$2I_a = \frac{V_S K(1-K)}{fL}$$

$$\frac{2KV_S}{R} = \frac{V_S K(1-K)}{fL}$$

Which gives the critical value of inductor L_c as,

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

If V_c is the average capacitor voltage, the capacitor ripple voltage $\Delta V_c = 2V_a$

further, $\Delta V_c = \frac{V_a(1-K)}{8LCf^2}$

$$2\cancel{V_a} = \frac{\cancel{V_a}(1-K)}{8LCf^2}$$

Which gives critical value of capacitor C_c as

$$\boxed{C_c = C = \frac{1-K}{16Lf^2}}$$