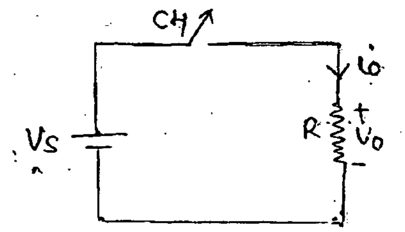
Choppers

fixed dc $\longrightarrow$ variable dc
(V_s) $\qquad$ (V_0)

(1) Step down chopper → ($V_0 < V_s$) (Buck converter)

For R lod →

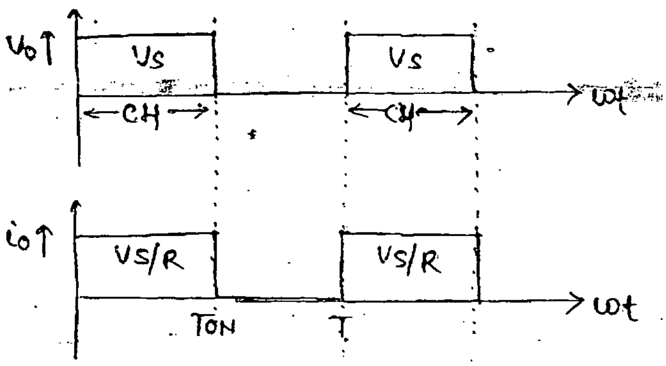


$V_0 = V_s\left(\frac{T_{ON}}{T}\right)$

$V_0 = \alpha V_s$

$\boxed{V_{or} = \sqrt{\alpha}\, V_s}$

$\alpha = \frac{T_{ON}}{T}$
(duty cycle)



Fourier Series For o/p voltage.

$$V_0 = \alpha V_s + \sum_{n=1}^{\infty} \frac{2V_s}{n\pi} \sin \pi n\alpha . \sin(n\omega t + \phi_n)$$

where $\phi_n = \tan^{-1}\left(\frac{\cos n\alpha}{\sin \pi n\alpha}\right)$

$$V_{on} = \frac{2V_s}{n\pi} \sin n\pi\alpha \sin(n\omega t + \phi_n)$$

$V_{on} = 0$. then $n\alpha = 1$

$\boxed{\alpha = \frac{1}{n}}$ cond^n to eliminate n^{th} harmonics

$$FF = \frac{V_{or}}{V_0} = \frac{\sqrt{\alpha}\, V_s}{\alpha V_s}$$

$$\boxed{FF = \frac{1}{\sqrt{\alpha}}}$$

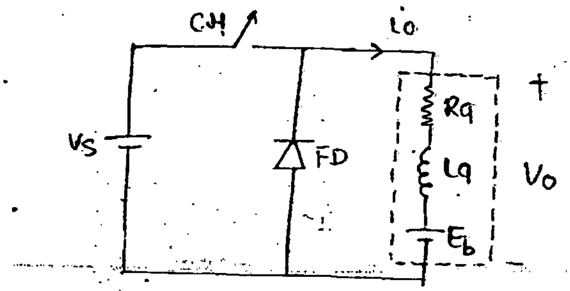
$V_{RF} = \sqrt{FF^2 - 1}$

$$\downarrow VRF = \sqrt{\frac{1}{\alpha\uparrow} - 1}$$

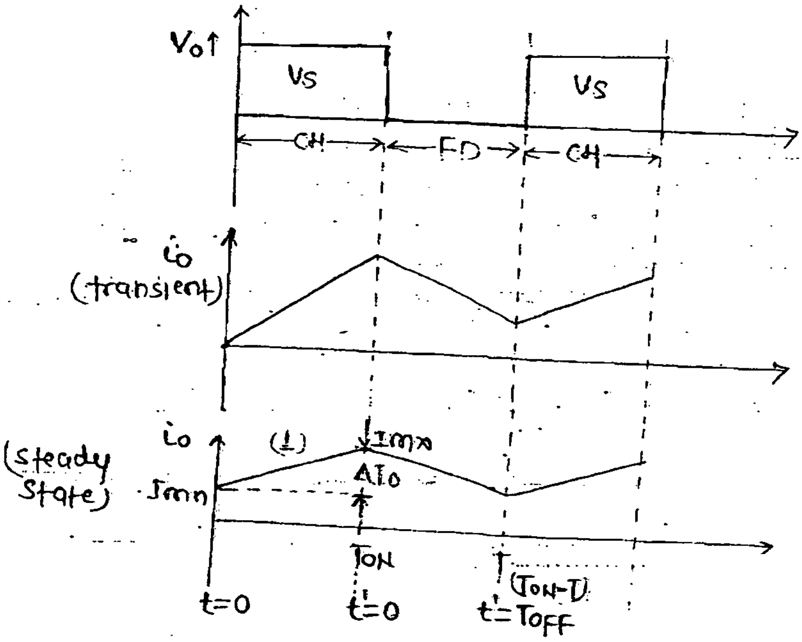
$$\boxed{\alpha\uparrow,\ VRF\downarrow\ \therefore\ \text{Harmonics}\downarrow}$$

* If it is contineous conduction there is no effect of back emf in the o/p voltage waveform.
Therefore the o/p vol. waveform is remain same for <u>RL & RLE load.</u>

<u>For RLE load →</u>



DC motor



at transient the value of current will 1st starts from 0 value & then goes to steady state value

$$V_o = V_S\left(\frac{T_{ON}}{T}\right)$$

$$\left.\begin{array}{l}\boxed{V_o = \alpha V_S}\\ \boxed{V_{or} = \sqrt{\alpha}\, V_S}\end{array}\right\} \text{RL \& RLE}$$

$$I_o = \frac{V_o - E_b}{R_a}$$

$$\boxed{I_o = \frac{\alpha V_S - E_b}{R_a}} \rightarrow \text{RLE}$$

$$\boxed{I_o = \frac{\alpha V_S}{R_a}} \rightarrow \text{RL}$$

* Avg. current does not depand on load inductance but the ripple current depands on the load inductance.

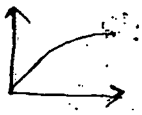
* mod (I.) $(0 \le t \le T_{ON})$

CH → ON (KVL)

$$V_s = R_a i_o + L_a \frac{di_o}{dt} + E_b$$

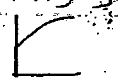
$$V_s - E_b = R_a i_o + L_a \frac{di_o}{dt}$$

$$i_o = \frac{V_s - E_b}{R_a}\left(1 - e^{-t/\tau_a}\right) \quad \text{[eq}^n \text{ From starting to 0] (transient)}$$



$$\left(\tau_a = \frac{L_a}{R_a}\right)$$

$$i_o = \frac{V_s - E_b}{R_a}\left(1 - e^{-t/\tau_a}\right) + I_{mn} e^{-t/\tau_a} \quad \text{[From the } I_{mn} \text{ value (steady state)]} \quad \text{--- (i)}$$



$$I_{mx} = \frac{V_s - E_b}{R_a}\left(1 - e^{-T_{ON}/\tau_a}\right) + I_{mn} e^{-T_{ON}/\tau_a} \quad \text{---- (ii)}$$

mode (II) → $(T_{ON} \le t \le T)$ (or) $(0 \le t' \le T_{OFF})$

FD → ON ∴ (KVL)

$$R_a i_o + L_a \frac{di_o}{dt'} + E_b = 0$$

$$-E_b = R_a i_o + L_a \frac{di_o}{dt'}$$

$$i_o = \frac{-E_b}{R_a}\left(1 - e^{-t'/\tau_a}\right) + I_{mx} e^{-t'/\tau_a} \quad \text{----- (iii)}$$

$$I_{mn} = \frac{-E_b}{R_a}\left(1 - e^{-T_{OFF}/\tau_a}\right) + I_{mx} e^{-T_{OFF}/\tau_a} \quad \text{------ (iv)}$$

By solving the eq^n (ii) & (iv) we can find the values of I_{mx} & I_{mn}

$$I_{mx} = \frac{V_s}{R_a}\left[\frac{1 - e^{-T_{ON}/\tau_a}}{1 - e^{-T/\tau_a}}\right] - \frac{E_b}{R_a} \quad \text{--- (V)}$$

$$I_{mn} = \frac{V_s}{R_a}\left[\frac{e^{T_{ON}/\tau_a} - 1}{e^{T/\tau_a} - 1}\right] - \frac{E_b}{R_a} \quad \text{----- (VI)}$$

Ripple current = $I_{max} - I_{min}$

$$\Delta I_0 = \frac{V_s}{R_q}\left[\frac{(1-e^{-T_{ON}/\tau_q})}{(1-e^{-T/\tau_q})} - \frac{(e^{T_{ON}/\tau_q}-1)}{(e^{T/\tau_q}-1)}\right]$$

$$\Delta I_0 = \frac{V_s}{R_q}\left[\frac{(1-e^{-T_{ON}/\tau_q})(1-e^{-T_{OFF}/\tau_q})}{(1-e^{-T/\tau_q})}\right] \quad \boxed{(T = T_{OFF}+T_{ON})}$$

$$\Delta I_0 = \frac{V_s}{R_q}\left[\frac{(1-e^{-\alpha T/\tau_q})(1-e^{-(1-\alpha)T/\tau_q})}{1-e^{-T/\tau_q}}\right] \quad \boxed{\begin{array}{l} T_{ON} = \alpha T \\ T_{OFF} = (1-\alpha)T \end{array}}$$

for max^m value of the max^m Ripple current

$$\frac{d(\Delta I_0)}{d\alpha} = \frac{d}{d\alpha}\left\{\frac{V_s}{R_q}\left[\frac{(1-e^{-\alpha T/\tau_q})(1-e^{-(1-\alpha)T/\tau_q})}{(1-e^{-T/\tau_q})}\right]\right\} = 0$$

$$\boxed{\alpha = 0.5}$$

$$(\Delta I_0)_{max} = \frac{V_s}{R_q}\left[\frac{(1-e^{-0.5T/\tau_q})(1-e^{-0.5T/\tau_q})}{(1-e^{-T/\tau_q})}\right]$$

$$(\Delta I_0)_{max} = \frac{V_s}{R_q}\tanh\frac{T}{4\tau_q} \qquad (\tanh x = x)$$

$$(\Delta I_0)_{max} = \frac{V_s}{R_q}\times\frac{T}{4\tau_q} = \frac{V_s}{\cancel{R_q}}\times\frac{T}{4\times\frac{L_q}{\cancel{R_q}}} = \frac{V_s}{F}\times\frac{1}{4L_q}$$

$$\boxed{(\Delta I_0)_{max} = \frac{V_s}{4F \cdot L_q}}$$

(max^m value of Ripple current at $\alpha = 0.5$)

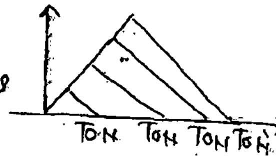
(1.) $\downarrow(\Delta I_0) \propto \dfrac{1}{F(L\uparrow)}$ (But equipment size will increase)

* By increasing the load inductance the ripple current reduce.

(2.) $\downarrow(\Delta I_0) \propto \dfrac{1}{(\uparrow F)L}$

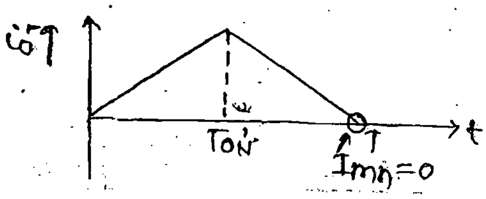
* At high chopping freq we can eliminate the ripple current without increases the size of inductor.
* smps operates based on the above chopper principle.
* At low values of T_{ON} it gives discontineous.

α' = duty cycle limit for contineous



* Duty cycle limit for contineous conduction →

* α' is the duty cycle at the boundary between contineous & dis-contineous conduction.



$$\alpha' = \frac{T'_{ON}}{T}$$

at $t=T$, $I_{mn}=0$

$$\frac{V_s}{R_a}\left[\frac{e^{T'_{ON}/\tau_a}-1}{e^{T/\tau_a}-1}\right]-\frac{E_b}{R_a}=0$$

$$\frac{V_s}{\cancel{R_a}}\left[\frac{e^{T'_{ON}/\tau_a}-1}{e^{T/\tau_a}-1}\right]=\frac{E_b}{\cancel{R_a}}$$

$$\left[\frac{e^{T'_{ON}/\tau_a}-1}{e^{T/\tau_a}-1}\right]=\frac{E_b}{V_s}$$

$$(e^{T'_{ON}/\tau_a}-1)=m(e^{T/\tau_a}-1) \qquad \left(\frac{E_b}{V_s}=m\right)$$

$$e^{(T'_{ON}/\tau_a)}=1+m(e^{T/\tau_a}-1)$$

$$\frac{T'_{ON}}{\tau_a}=\ln\left[1+m(e^{T/\tau_a}-1)\right]$$

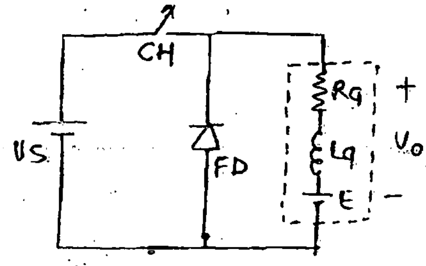
$$\alpha=\frac{T'_{ON}}{T}=\frac{\tau_a}{T}\ln\left[1+m(e^{T/\tau_a}-1)\right]$$

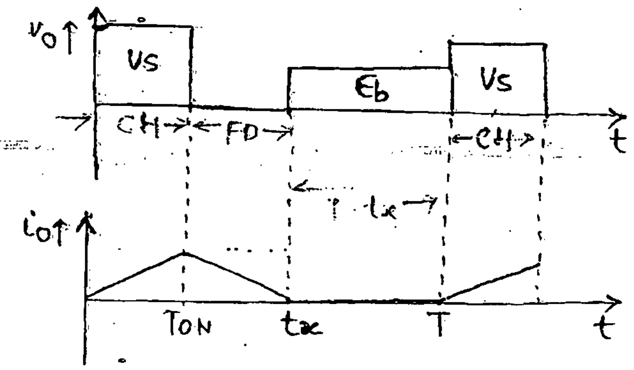
$$\boxed{\alpha'=\frac{T'_{ON}}{T}=\frac{\tau_a}{T}\ln\left[1+m(e^{T/\tau_a}-1)\right]}$$

$\alpha < \alpha' \longrightarrow$ discontineous

$\alpha > \alpha' \longrightarrow$ Contineous

* Discontineous Conduction →





$$V_0 = V_S\left(\frac{T_{ON}}{T}\right) + E_b\left(\frac{T-t_x}{T}\right)$$

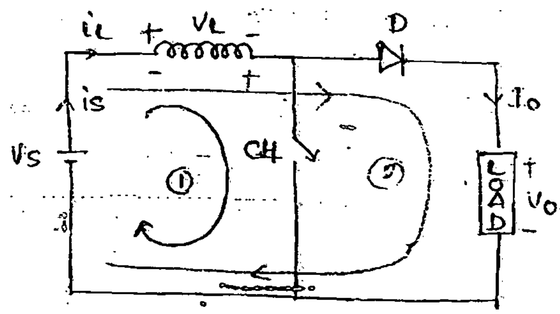
($t_x \rightarrow$ Extinction time)

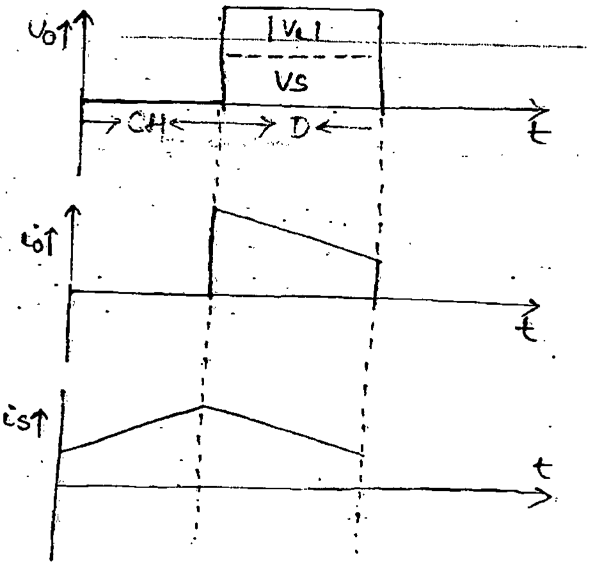
$$\boxed{V_0 = V_S\alpha + E_b\left(1-\frac{t_x}{T}\right)}$$

$$V_{or} = \left[V_S^2\left(\frac{T_{ON}}{T}\right) + E_b^2\left(\frac{T-t_x}{T}\right)\right]^{1/2}$$

$$\boxed{V_{or} = \left[\alpha V_S^2 + E_b^2\left(1-\frac{t_x}{T}\right)\right]^{1/2}}$$

Step up chopper →





(I) $0 \leq t \leq T_{ON}$ →

CH → ON, D → OFF, $V_0 = 0$

$i_0 = 0$

$$V_S = V_L = L\frac{di_S}{dt}$$

L → stores energy

(II.) $T_{ON} \le t \le T \rightarrow$

CH → OFF, D → ON, $i_s = i_o$

$\left.\begin{array}{c}\text{Source}\\ \&\\ \frac{1}{2}Li^2\end{array}\right\} \xrightarrow{P}$ Load

L → Releasing energy

$V_o = V_s + |V_L|$

$$\boxed{V_o = \frac{V_s}{1-\alpha}}$$

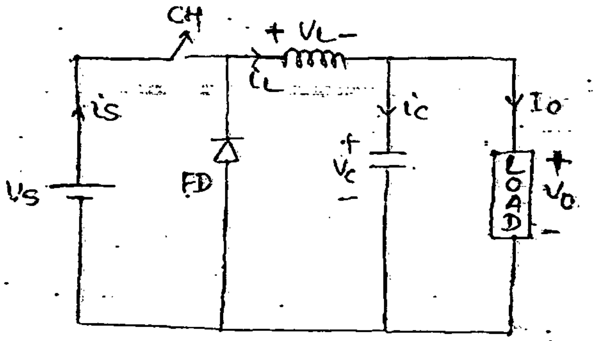
$\alpha < 1$, $V_o > V_s$

Step up chopper
Boost converter

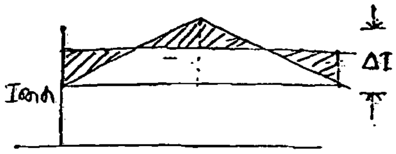
* In step up chopper power flows from low vol. side to high voltage side
* Step up chopper principle can be used for regenerative braking of dc m/c.

Choppers with Filters → * In order to reduce the harmonics & improve the quality of o/p waveform we have to use filters.

Step down chopper (Buck converter) → For 1st order low pass filter we use resistance but in the resistance power loss occurs.



i_L → DC Component $(I_L)_{avg}$
→ AC Component (At multiple Harmonic freq.)



$$\boxed{Area = \frac{\Delta I}{2} + I_{mn}}$$

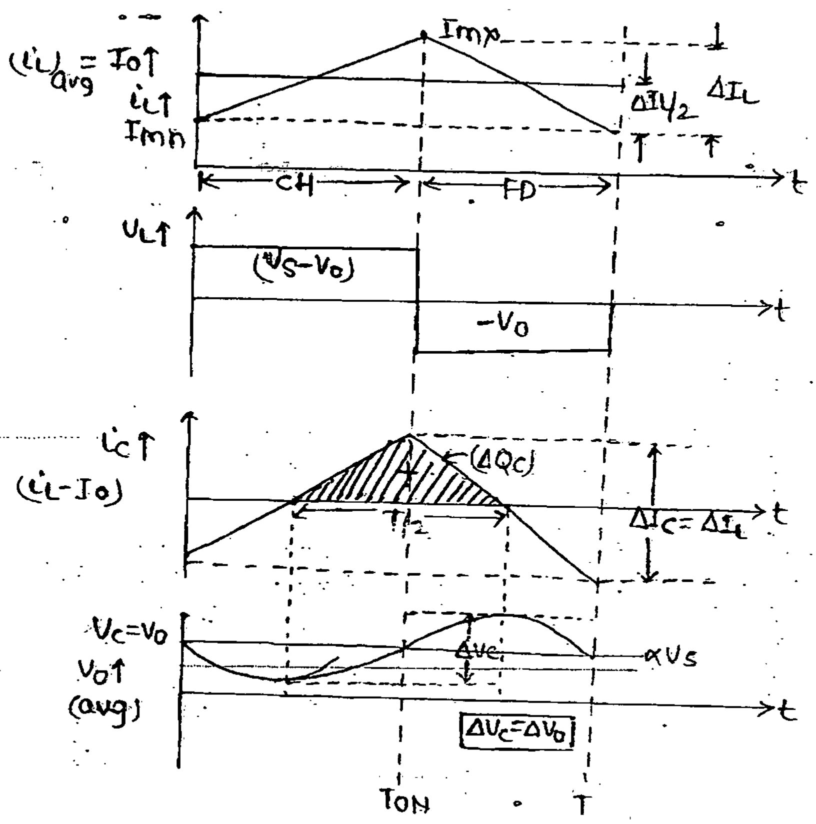
* Let us assume very large value of filter capacitance. So that the o/p vol remains almost constant.

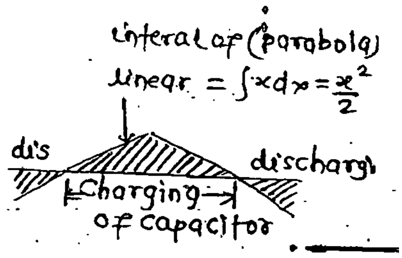
$$X_C = \frac{1}{\omega C \uparrow} \simeq 0 \text{ (Ac comp) (short circuited)}$$

$$X_C = \frac{1}{\omega C} \simeq \infty \text{ (dc comp.) (open circuited)}$$

* Capacitor will only allow only AC comp. (Ripple)
* All the AC comp. will bypass through Capacitor then;

$$\boxed{(\Delta I_L) = (\Delta I_C)}$$





(1) $0 \le t \le T_{ON} \rightarrow$ CH → ON

$$-V_S + V_L + V_0 = 0$$

$$V_L = V_S - V_0$$

$$L\frac{di_L}{dt} = V_S - V_0$$

$$\frac{di_L}{dt} = \frac{V_S - V_0}{L}$$

$$\int_{I_{mn}}^{I_{mx}} di_L = \frac{V_S - V_0}{L}\int_0^{T_{ON}} dt$$

$$\Delta I_L = \frac{V_S - V_0}{L} \cdot T_{ON} \qquad \left\{ \begin{aligned} T_{ON} &= \alpha T \\ &= \frac{\alpha}{f} \end{aligned} \right\}$$

$$= \frac{V_S - \alpha V_S}{L} \cdot \frac{\alpha}{f}$$

$$\boxed{\Delta I_L = \frac{\alpha(1-\alpha)V_S}{fL}}$$

$$\boxed{(\Delta I_L)_{max} = \frac{V_S}{4fL}} \rightarrow \text{at } \alpha = 0.5$$

(II) $T_{ON} \le t \le T \rightarrow$ CH $\rightarrow$ OFF, FD $\rightarrow$ ON

$$+V_L + V_0 = 0$$

$$V_L = -V_0$$

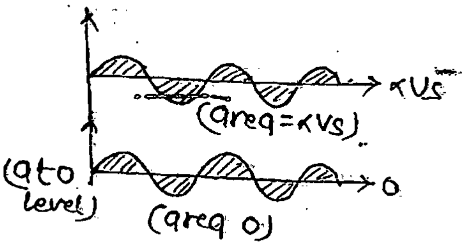
$$(V_L)_{avg} = 0$$

+ve area + (-ve) area = 0

$$(V_S - V_0) T_{ON} + V_0 T_{OFF} = 0$$

$$V_S T_{ON} = V_0 [T_{ON} + T_{OFF}]$$

$$\boxed{V_0 = V_S \alpha} \qquad \alpha = \frac{T_{ON}}{T}$$



From the area of Δ in the waveform

$$\Delta Q = C \cdot \Delta V_C$$

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

where $\Delta Q = \frac{1}{2} \cdot \frac{T}{2} \cdot \frac{\Delta I_L}{2}$

$$\Delta Q = \frac{\Delta I_L}{8f}$$

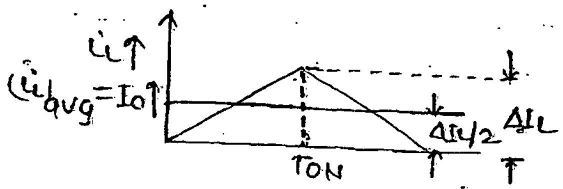
$$\boxed{\Delta V_C = \frac{\Delta I_L}{8fC}}$$

$$\boxed{\Delta V_C = \frac{\alpha(1-\alpha) V_S}{8 f^2 LC}} \quad \text{-----(2.)}$$

* If we increase the value of $f\uparrow$ then ΔV_C will decrease. & we will get pure dc current ($\Delta V_C = 0$)

Critical inductance $\rightarrow$ (L_C) It is the value of inductance at which I_L waveform is just discontineous.

If L



$$I_0 = \frac{\Delta I_L}{2}$$

$$\frac{\alpha V_S}{R} = \frac{\alpha(1-\alpha) V_S}{2fLC}$$

$$\boxed{L_C = \frac{(1-\alpha) R}{2f}} \quad \text{-------(3.)}$$

Critical Capacitance (C_c) → It is the value of capacitance ~~At~~ which the v_c waveform is just discontineous.

$$V_o = \frac{\Delta V_c}{2} \ (\text{at } C_c)$$

$$V_o = \frac{\alpha(1-\alpha)V_s}{16f^2LC}$$

$$\cancel{\alpha V_s} = \frac{\alpha(1-\alpha)\cancel{V_s}}{16f^2LC_c}$$

$$\boxed{C_c = \frac{(1-\alpha)}{16f^2L}} \quad \text{------(4.)}$$

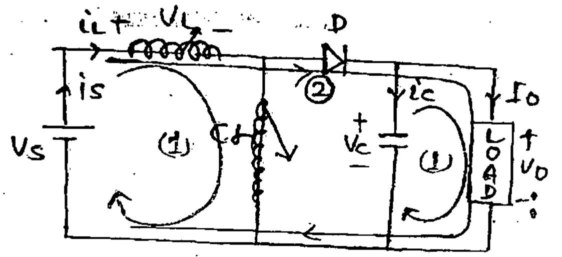
$$P_o = P_{in}$$

$$V_oI_o = V_sI_s$$

$$\frac{V_o}{V_s} = \frac{I_s}{I_o} = \alpha$$

$$\boxed{I_s = \alpha I_o}$$

* Step up chopper (Boost Converter) →



$i_L = i_c + i_o$

$(I_L)_{min} > (I_o)$

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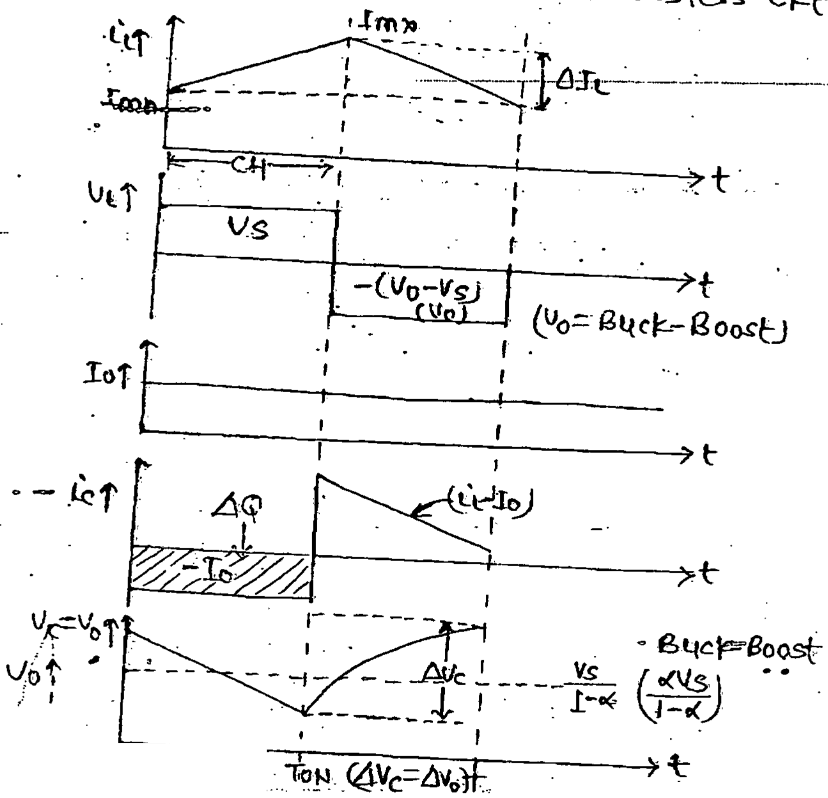
* Let us assume large value of Filter capacitance. So that the o/p vol. remains const

* Let us assume const load current & it is a lossless ckt (ideal ckt)



(I.) $0 \le t \le T_{ON} \rightarrow$

$CH \rightarrow ON,\ D \rightarrow OFF$

$\boxed{i_c = -I_o}$

$V_L = V_S$

$L\frac{di_L}{dt} = V_S$

$$\int_{I_{mn}}^{I_{mx}} di_L = \int_0^{T_{ON}} \frac{V_S}{L}\,dt$$

$$\Delta I_L = \frac{V_S}{L} \cdot T_{ON}$$

$$\boxed{\Delta I_L = \frac{\alpha V_S}{fL}} \text{ ----(1)}$$

(II.) $T_{ON} \le t \le T \rightarrow$

$CH \rightarrow OFF;\ D \rightarrow ON$

$\boxed{i_L = i_c + I_o}$

$-V_S + V_L + V_o = 0$

$V_L = V_S - V_o$

* $V_L = -(V_S - V_o)$

* $(V_o > V_S)$ step up

* $(V_L)_{avg} = 0$

$V_S T_{ON} = (V_o - V_S) T_{OFF} = 0$

$V_S(T_{ON} + T_{OFF}) = V_o T_{OFF}$

$V_S \cancel{T} = V_o (1-\alpha) \cancel{T}$

$$\boxed{V_o = \frac{V_S}{1-\alpha}}$$

$P_o = P_{in}$

$V_o I_o = V_S I_S$

$$\boxed{\frac{V_o}{V_S} = \frac{I_S}{I_o} = \frac{1}{(1-\alpha)}}$$

$$\boxed{I_S = \frac{I_o}{(1-\alpha)}}$$

$\Delta Q = C \Delta V_C$

$$\Delta V_C = \frac{\Delta Q}{C} = \frac{I_o T_{ON}}{C}$$

$T_{ON} = \alpha T = \frac{\alpha}{f}$

$$\boxed{\Delta V_C = \frac{\alpha I_o}{fC}} \text{ ----(2)}$$

Critical inductance (L_c) →

$$I_o = \frac{\Delta I_L}{2} \quad (\text{at } L_c)$$

$$\frac{V_s}{(1-\alpha)R} = \frac{\alpha V_s}{2 f L_c}$$

$$\boxed{L_c = \frac{\alpha(1-\alpha)R}{2f}} \quad \text{------} (3.)$$

Critical capacitance (C_c) →

$$V_o = \frac{\Delta V_c}{2}$$

$$I_o R = \frac{\alpha I_o}{2 f C_c}$$

$$\boxed{C_c = \frac{\alpha}{2 f R}} \quad \text{------} (4.)$$

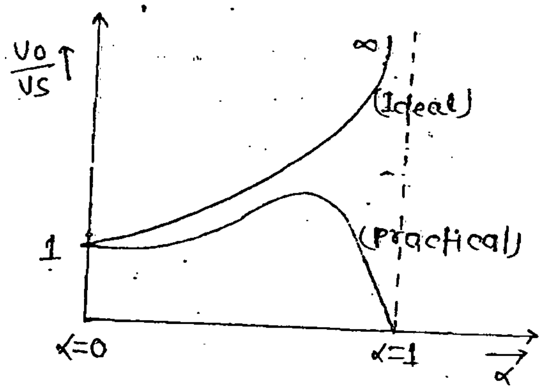
Non-ideal case → (Practical)

r → internal resistance of inductance

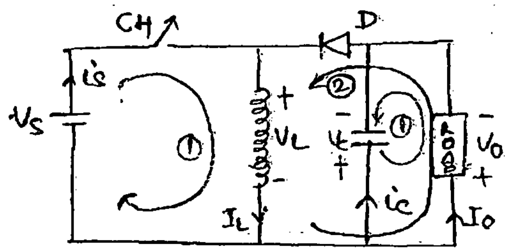
R → Load resistance.

$$\boxed{V_o = \frac{V_s(1-\alpha)}{\frac{r}{R} + (1-\alpha)^2}} \quad \text{(Not in syllabus)}$$

If question is ask in the form of internal ~~inductance~~ resistor of inductance



Step down/up chopper (Buck-Boost Converter) →



* Let us assume constant o/p vol. & current & it is a lossless ckt.

(I) $0 \le t \le T_{ON}$ → CH → ON, D → OFF

$$i_c = -I_o$$

$$V_L = V_s$$

$$L\frac{di_L}{dt} = V_s$$

$$\int_{I_{mn}}^{I_{mp}} di_L = \frac{V_s}{L}\int_0^{T_{ON}} dt$$

$$\boxed{\Delta I_L = \frac{\alpha V_s}{fL}} \quad \text{----(i)}$$

(II) $T_{ON} \le t \le T$ →

CH → OFF, D → ON

$$i_L = i_c + I_o$$

$$+V_L + V_o = 0$$

$$V_L = -V_o$$

$$(V_L)_{avg} = 0$$

$$V_s T_{ON} - V_o T_{OFF} = 0$$

$$V_s T_{ON} = V_o T_{OFF}$$

$$V_s(\alpha T) = V_o(1-\alpha)T$$

$$\boxed{V_o = \frac{\alpha V_s}{(1-\alpha)}}$$

$$V_o I_o = V_s I_s$$

$$\boxed{\frac{V_o}{V_s} = \frac{I_s}{I_o} = \frac{\alpha}{(1-\alpha)}}$$

$$\boxed{I_s = \frac{\alpha I_o}{(1-\alpha)}}$$

$$\Delta Q = C\cdot\Delta V_c$$

$$\Delta V_c = \frac{\Delta Q}{C} = \frac{I_o T_{ON}}{C}$$

$$\boxed{\Delta V_c = \frac{\alpha I_o}{fC}} \quad \text{----(ii)}$$

Critical inductance (L_c) →

$$I_o = \frac{\Delta I_L}{2} \quad (\text{at } L_c)$$

$$\frac{\alpha V_s}{(1-\alpha)R} = \frac{\alpha V_s}{2 f L_c}$$

$$\boxed{L_c = \frac{(1-\alpha)R}{2f}} \quad \text{----(3)}$$

Critical Capacitance (C_c) →

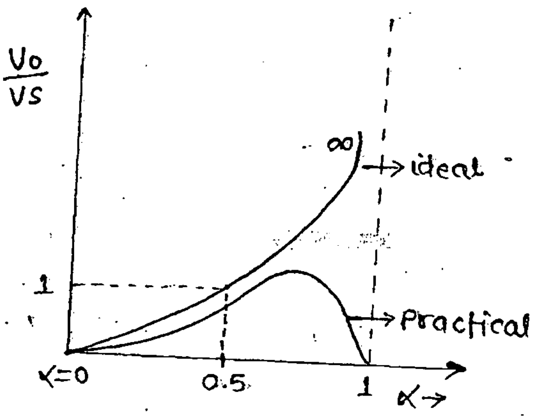
$$V_o = \frac{\Delta V_c}{2}$$

$$I_o R = \frac{\alpha I_o}{2 f C_c}$$

$$\boxed{C_c = \frac{\alpha}{2fR}} \quad \text{----(4.)}$$

Non-ideal case →

$$\boxed{V_o = \frac{V_s \alpha (1-\alpha)}{\frac{r}{R} + (1-\alpha)^2}}$$

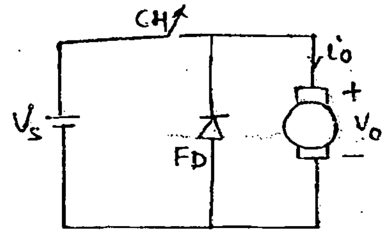


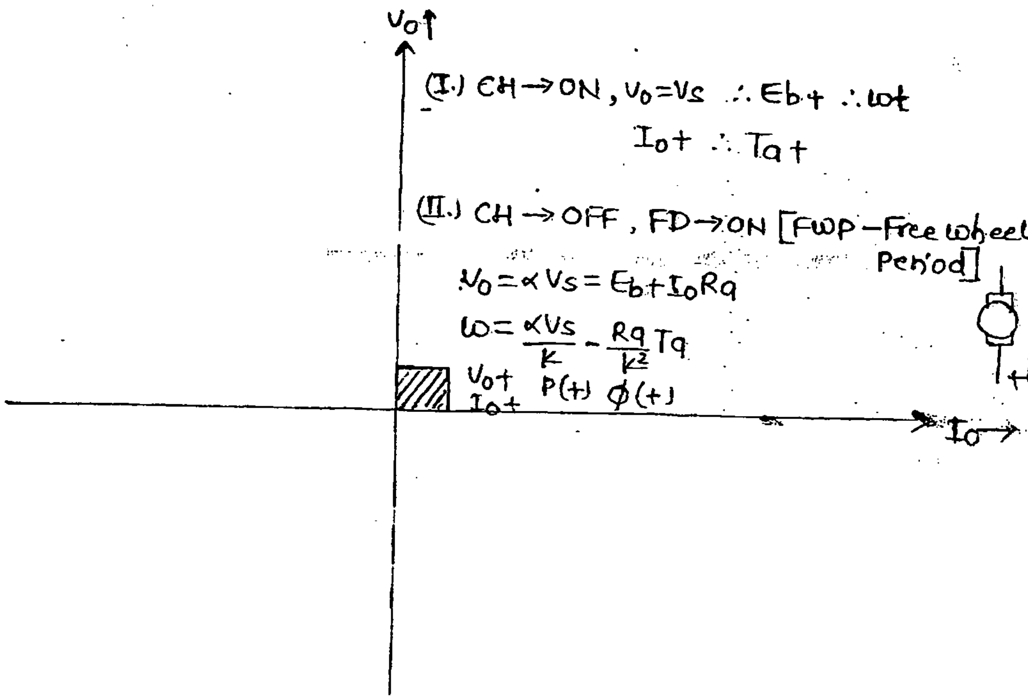
$$\boxed{\begin{array}{l} \alpha < 0.5,\ V_o < V_s \\ \alpha > 0.5,\ V_o > V_s \end{array}}$$

Parameters	Step down (Buck Con^r)	Step up chopper (Boost Con^r)	Step up/down chopper (Buck-Boost Con^r)
* ΔI_L	$\frac{\alpha(1-\alpha)V_s}{fL}$	$\frac{\alpha V_s}{fL}$	$\frac{\alpha V_s}{fL}$
* $(\Delta I_L)_{max}$ $(\alpha=0.5)$	$\frac{V_s}{4fL}$	$\frac{V_s}{2fL}$	$\frac{V_s}{2fL}$
** V_o	αV_s	$\frac{V_s}{(1-\alpha)}$	$\frac{\alpha V_s}{(1-\alpha)}$
* ΔQ_c	$\frac{\Delta I_L}{8f}$	—	—
* ΔV_c	$\frac{\alpha(1-\alpha)V_s}{8f^2LC}$	$\frac{\alpha I_o}{fC}$	$\frac{\alpha I_o}{fC}$
* L_c	$\frac{(1-\alpha)R}{2f}$	$\frac{\alpha(1-\alpha)R}{2f}$	$\frac{(1-\alpha)R}{2f}$
* C_c	$\frac{(1-\alpha)}{16f^2LC}$	$\frac{\alpha}{2fR}$	$\frac{\alpha}{2fR}$
** Ratio	$\frac{V_o}{V_s}=\frac{I_s}{I_o}=\alpha$	$\frac{V_o}{V_s}=\frac{I_s}{I_o}=\frac{1}{(1-\alpha)}$	$\frac{V_o}{V_s}=\frac{I_s}{I_o}=\frac{\alpha}{1-\alpha}$
** I_s	αI_o	$I_o\left(\frac{1}{1-\alpha}\right)$	$\frac{\alpha I_o}{(1-\alpha)}$
* V_o (practical)	$\cancel{V_s/\alpha}$ —	$\frac{V_s(1-\alpha)}{\frac{r}{R}+(1-\alpha)^2}$	$\frac{V_s\alpha(1-\alpha)}{\frac{r}{R}+(1-\alpha)^2}$

[redacted]ation of chopper based on quadrant operation →

[redacted]st quadrant chopper :(Type A)→ (step down chopper)





(I.) CH → ON , $V_o = V_s$ ∴ $E_b\uparrow$ ∴ $\omega\uparrow$

$I_o\uparrow$ ∴ $T_a\uparrow$

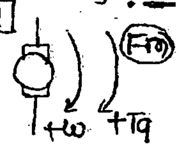
(II.) CH → OFF , FD → ON [FWP – Free wheeling Period]

$V_o = \alpha V_s = E_b + I_o R_a$

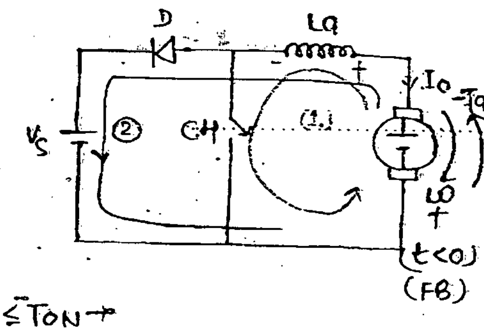
$\omega = \frac{\alpha V_s}{K} - \frac{R_a}{K^2} T_a$

$V_o\uparrow$ P(+) ϕ(+)

$I_o\uparrow$



(2.) 2nd quadarant Chopper (Type B) →



Let us assume that the m/c is running at rated speed in the forward dirn before t=0.

Brake energy at t=0 = $\frac{1}{2}J\omega^2$

(1.) $0 \le t \le T_{ON}$ →

CH → ON, D → OFF

($V_o = 0$) ∴ ($I_o -$), ∴ ($T_a -$)

$\frac{1}{2}J\omega^2 \rightarrow \frac{1}{2}Li^2$

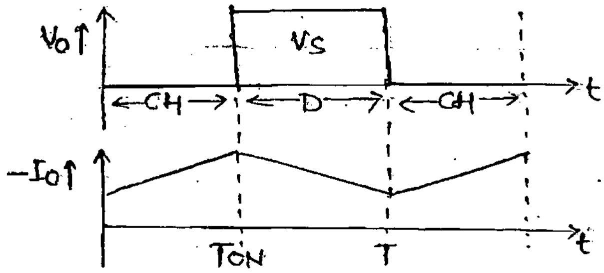
(II.) $T_{ON} \le t \le T$ →

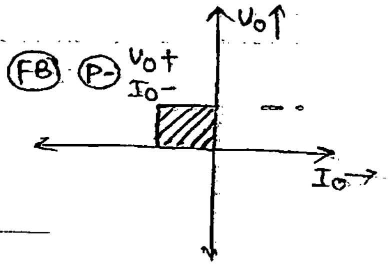
CH → OFF, D → ON

$\frac{1}{2}Li^2 \longrightarrow$ Source

L → releasing energy

$V_o = V_s$





Source $\xleftarrow{(P)}$ Brake energy

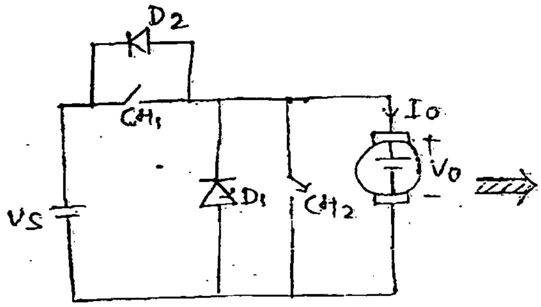
$\therefore$ Regenerative Braking

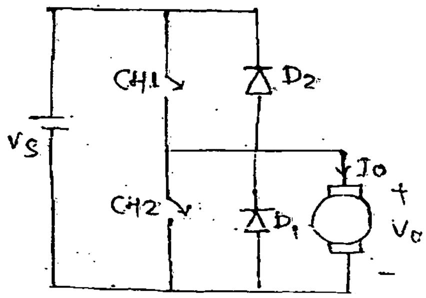
HV $\longleftarrow$ LV

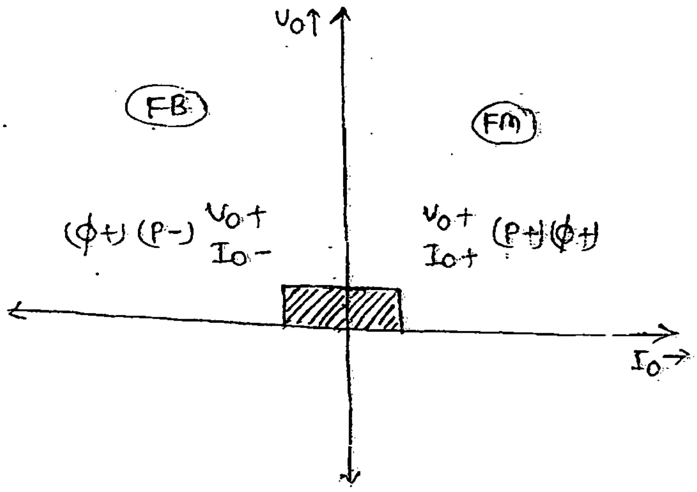
Regenerative Power $= V_o I_o \quad (V_o < V_s)$

$= (1-\alpha) V_s \cdot I_o$

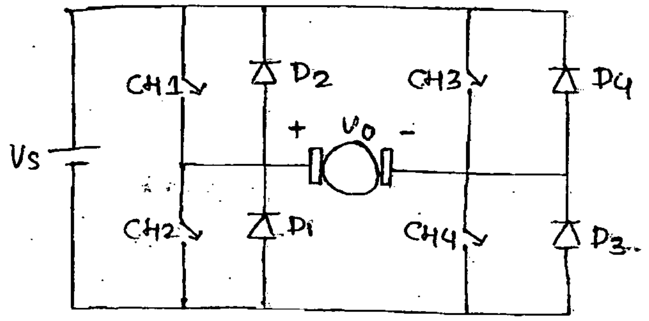
3.) Two quadrant Chopper →

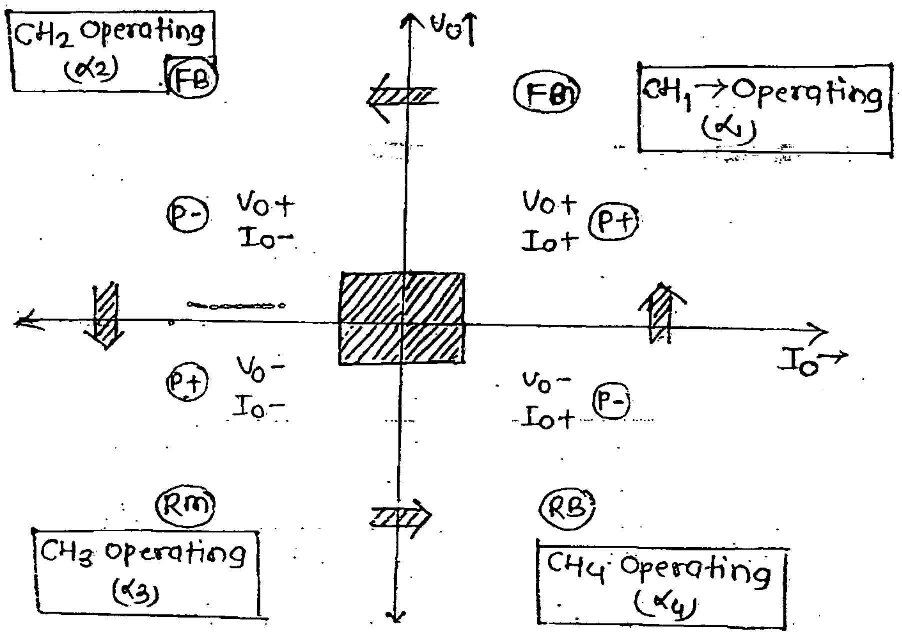






4. Four Quadrant Chopper →





(1) CH2, D3 → ON

$V_0 = 0$, ∴ I_0-, ∴ T_q-

$\frac{1}{2}J\omega^2 \rightarrow \frac{1}{2}Li^2$

(2) CH2 → OFF

D2, D3 → ON

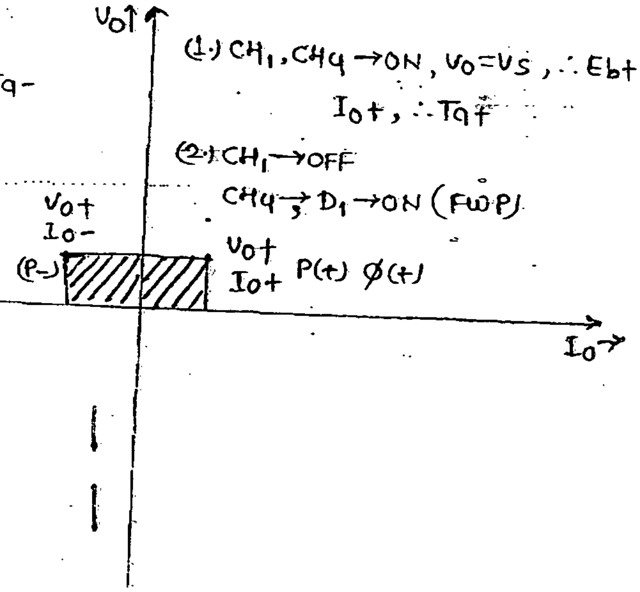
$\frac{1}{2}J\omega^2 \rightarrow$ source

(1) CH1, CH4 → ON, $V_0 = V_s$, ∴ E_b+, ∴ $\omega+$

I_0+, ∴ T_q+

(2) CH1 → OFF

CH4 → D1 → ON (FWP)



AC Voltage Controller

Fixed AC ⟶ Variable AC

V_0

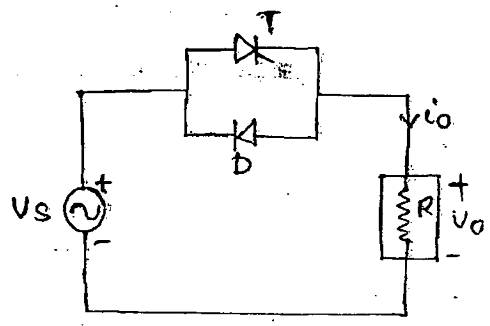
f (const)

(1) Phase Control tech.

(2) Integral cycle control (ON/OFF)

(1) Phase Control tech →

(i) Single phase half controlled AC vol. Controller →

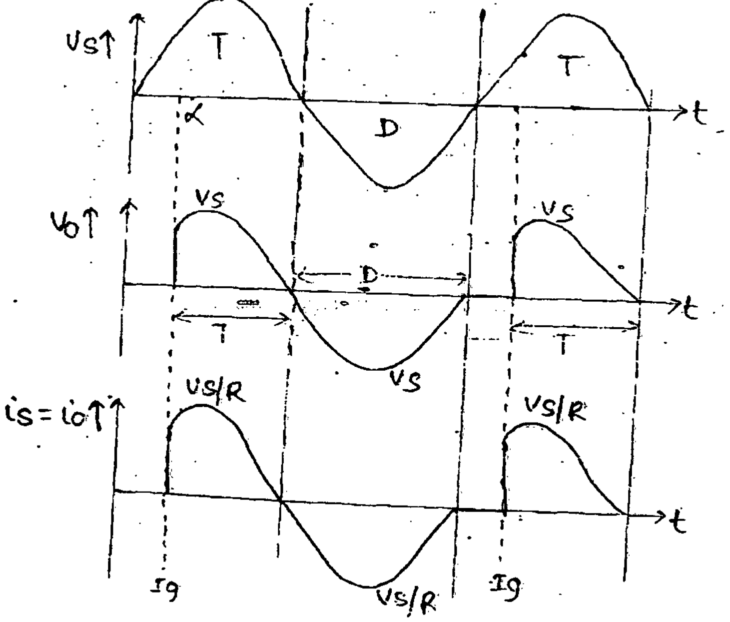


$$V_0 = \frac{1}{2\pi}\int_{\alpha}^{2\pi} V_m \sin\omega t \cdot d(\omega t)$$

$$\boxed{V_0 = \frac{V_m}{2\pi}[\cos\alpha - 1]}$$

$$\boxed{(I_s)_{avg} = I_0 = \frac{V_m}{2\pi R}[\cos\alpha - 1]}$$

$(I_s)_{avg}$ → Dc comp.



Drawback →

* The source current contains dc comp. & saturates the supply Xmer core. Therefore this type of AC vol. controllers are not prefered in applications.

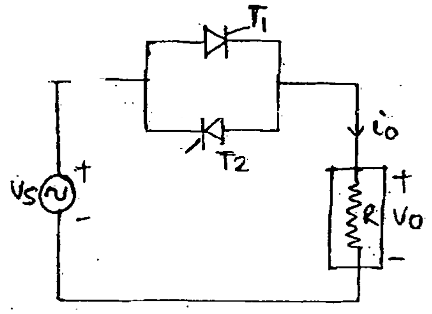
$$V_{or} = \left\{ \frac{1}{2\pi} \int_{\alpha}^{2\pi} V_m^2 \sin^2\omega t \cdot d(\omega t) \right\}^{1/2}$$

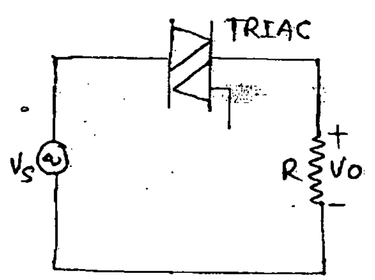
$$V_{or} = \frac{V_m}{2\sqrt{\pi}} \left\{ (2\pi - \alpha) + 1/2 \sin 2\alpha \right\}^{1/2}$$

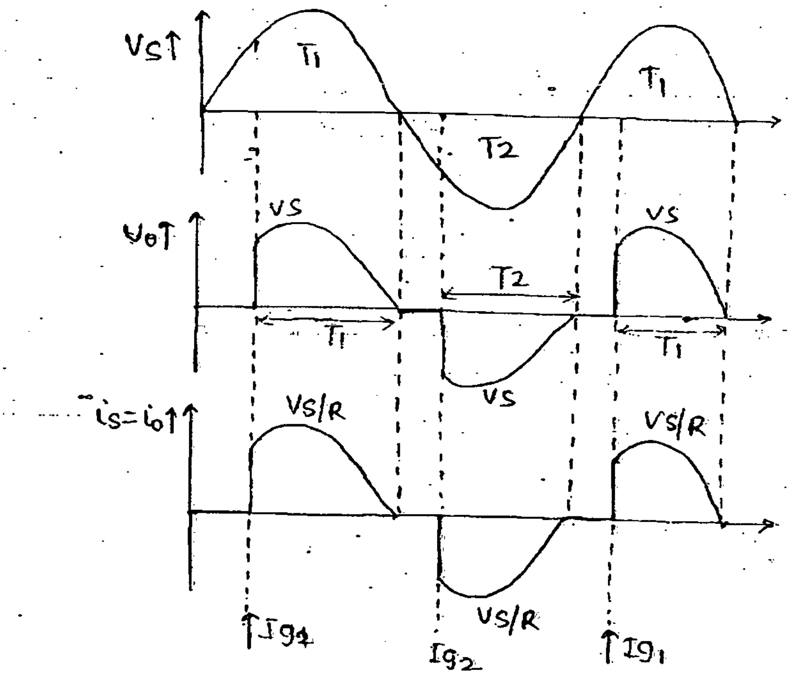
For R Load →

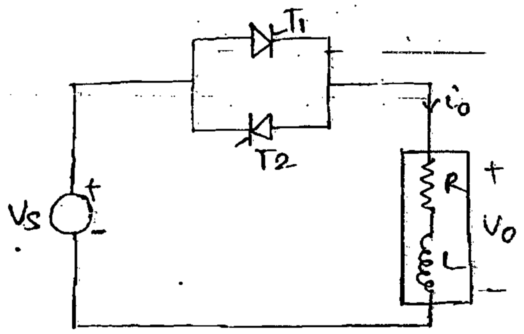
$$PF = \frac{V_{or}}{V_{sr}} = \frac{1}{\sqrt{2\pi}} \left\{ (2\pi - \alpha) + \frac{1}{2} \sin 2\alpha \right\}^{1/2}$$

(2) 1ϕ Full Controlled AC Voltage Controller →





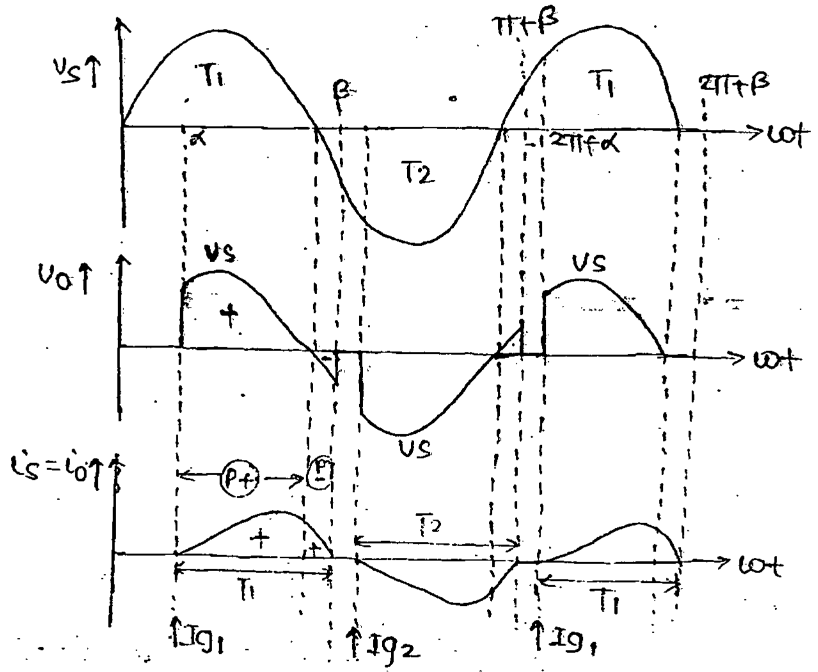




After reaching steady state,
i_o lags V_o by $\phi = \tan^{-1}\frac{\omega L}{R}$

(i) $\alpha > \phi$, V_o is controlled

(ii) $\alpha \le \phi$, V_o is uncontrolled.



(i) $\alpha > \phi$, V_o is controlled →

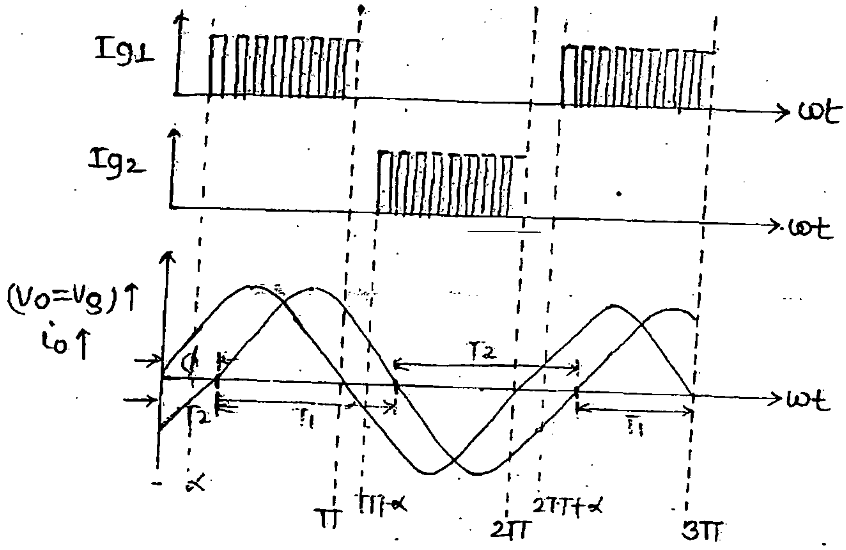
$$V_{or} = \frac{V_m}{\sqrt{2\pi}}\left[(\beta - \alpha) + \frac{1}{2}(\sin 2\alpha - \sin 2\beta)\right]^{1/2}$$

$$I_{or} = \frac{V_{or}}{|Z|} \qquad \text{where } |Z| = \sqrt{R^2 + (\omega L)^2}$$

(ii) $\alpha \le \phi$, V_o is Uncontrolled →

$$\boxed{(V_{or})_{max} = V_{sr} = \frac{V_m}{\sqrt{2}}}$$

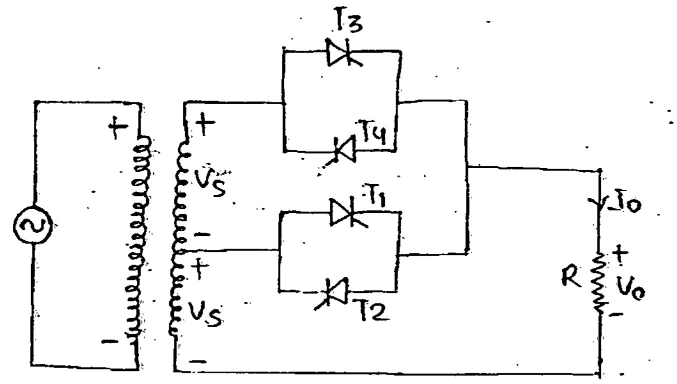
$$\boxed{(I_{or})_{max} = \frac{(V_{or})_{max}}{|Z|}}$$



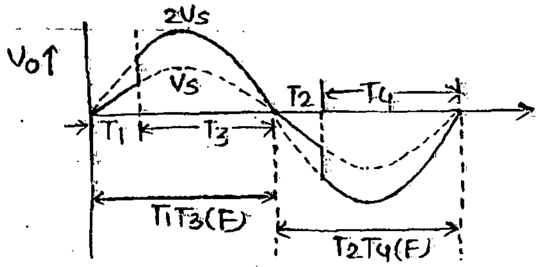
* If pulse gate signal is given tho thy. in AC vol. controller with inductive load then it may behave like half wave rectifier.
To rectify this prob. we must provide contineous gate pulse (or) high freq. gate pulse as shown in fig.

Drawback → In phase control tech. at high values of α harmonics distortion is higher & is operates at ~~high~~ low PF.

Two-stage AC vol. controller →



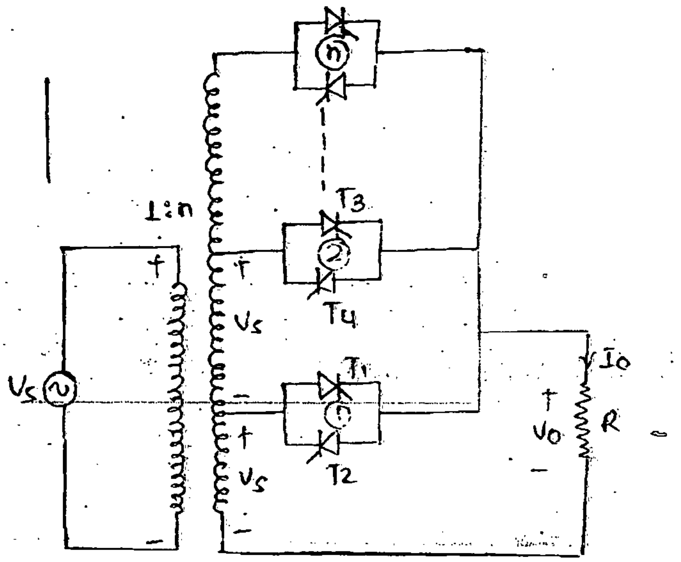
+ve $T_1 T_3$ (F)
−ve $T_2 T_4$ (F)

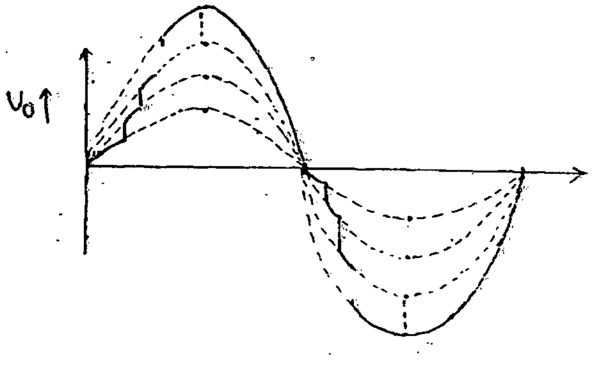


$$V_{or} = \left\{ \frac{1}{\pi} \left[\int_0^{\alpha} V_m^2 \cdot \sin^2\omega t \cdot d(\omega t) + \int_{\alpha}^{\pi} 4V_m^2 \cdot \sin^2\omega t \cdot d(\omega t) \right] \right\}^{1/2}$$

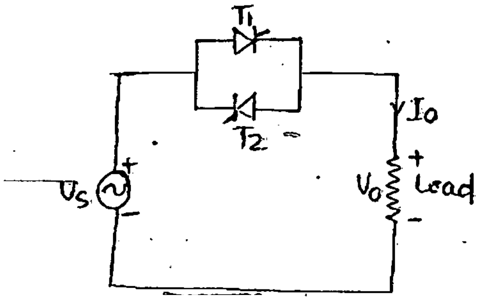
$$V_{or} = \frac{V_m}{\sqrt{2\pi}} \left\{ \left[\alpha - 1/2 \sin 2\alpha \right] + 4\left[(\pi - \alpha) + \frac{1}{2} \sin 2\alpha \right] \right\}^{1/2}$$

Multi-stage Ac Voltage Controller →



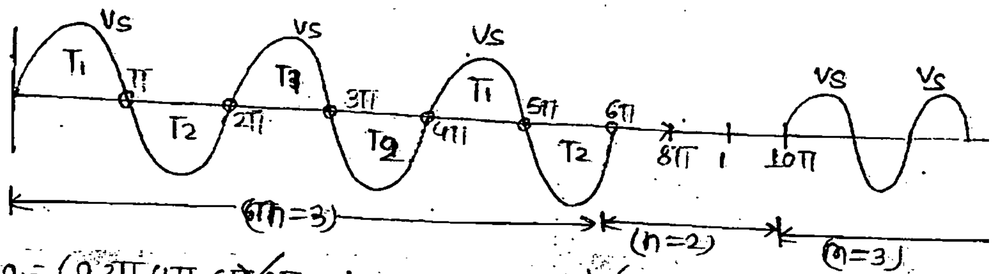


Integral cycle control → (ON/OFF)



m cycles → ON $(V_o = V_s)$ let $m = 3$

n cycles → OFF $(V_o = 0)$ $n = 2$



$Ig_1 = (0, 2\pi, 4\pi, \cancel{6\pi}, \cancel{8\pi}, 10\pi, 12\pi, 14\pi, \cancel{16\pi}, \cancel{18\pi} \ldots)$

$Ig_2 = (\pi, 3\pi, 5\pi, \cancel{7\pi}, \cancel{9\pi}, 11\pi, 13\pi, \cancel{17\pi}, \cancel{19\pi}, 21\pi \ldots)$

$$V_{or} = V_{sr} \left(\frac{m}{m+n}\right)^{1/2}$$

$$\boxed{V_{or} = \sqrt{K}\, V_{sr}} \qquad \left(K = \frac{m}{m+n}\right)$$

$$\boxed{PF = \sqrt{K}}$$

Application → It can be used for the AC loads with high time constant.
For eg:- It can be used for Indⁿ motor with high MI & mech. time constant.

Limitation → We can't get wide range of voltage control with this method.

* Cycloconverter →