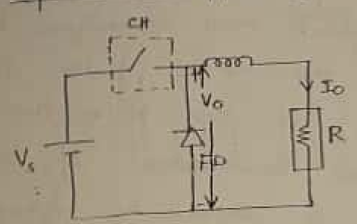
17/9/2011

Choppers

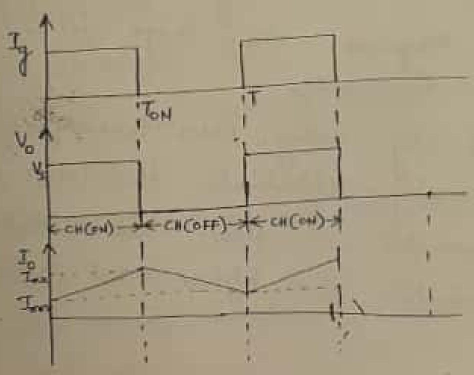
①

Fixed DC $\longrightarrow$ Variable DC

stepdown chopper $(V_o < V_s)$



$\rightarrow$ Inductance is added to reduce the ripple in the load current



L

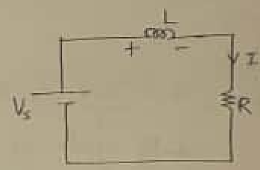
②

– Mode 1: 0 to T_{ON}

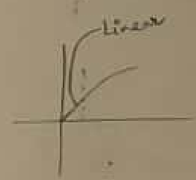
CH is ON

$V_o = V_s$

L will store energy



$V_s = Ri + L\frac{di}{dt}$



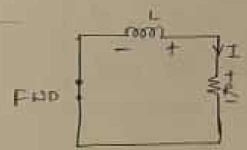
$P_{source} \longrightarrow P_{Load}$

$\left(\frac{1}{2}Li^2 + i^2R\right)$

Mode 2: T_{ON} to T

CH is OFF

$\frac{1}{2}Li^2 \rightarrow i^2R$



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→ $V_o = \frac{1}{T}\int_0^{T_{ON}} V_s \cdot dt$

$= V_s \cdot \frac{T_{on}}{T}$

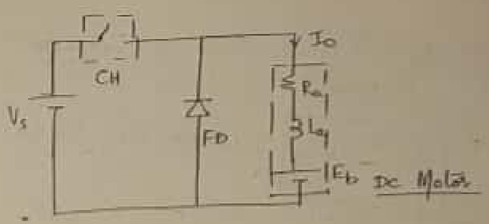
$$\boxed{V_o = \alpha V_s}$$

where, $\alpha = \frac{T_{on}}{T}$ is called duty cycle of chopper.

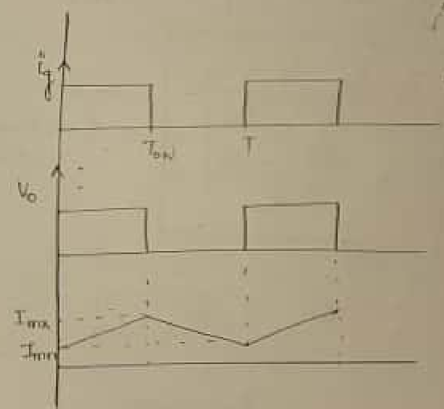
→ $V_{or}^2 = \frac{1}{T}\int_0^{T_{ON}} V_s^2 \, dt$

$= V_s^2 \cdot \frac{T_{on}}{T}$

$$\Rightarrow \boxed{V_{or} = \sqrt{V_s^2 \, \alpha} = \sqrt{\alpha} \cdot V_s}$$



① Continuous Conduction



$$\boxed{\begin{aligned} V_o &= \alpha V_s \\ V_{or} &= \sqrt{\alpha}\, V_s \end{aligned}}$$ → R, RL & RLE (Continuous Conduction)

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$$I_o = \frac{V_o}{R}$$

$$\boxed{I_o = \frac{\alpha V_s}{R}} \longrightarrow R, RL \text{ loads}$$

→ Inductor changes only the ripple but not average value of current

$$\boxed{\begin{aligned} I_o &= \frac{V_o - E_b}{R_a} \\ &= \frac{\alpha V_s - E_b}{R_a} \end{aligned}} \longrightarrow RLE \text{ (continuous conduction)}$$

6

$$I_{mx} = \frac{V_s}{R_a}\left[\frac{1 - e^{-T_{ON}/T_a}}{1 - e^{-T/T_a}}\right] - \frac{E_b}{R_a}$$

where, $T_a = \frac{L_a}{R_a}$

$$I_{mn} = \frac{V_s}{R_a}\left[\frac{e^{T_{ON}/T_a} - 1}{e^{T/T_a} - 1}\right] - \frac{E_b}{R_a}$$

Ripple current $= I_{mx} - I_{mn}$

$$= \frac{V_s}{R_a}\left[\frac{1 - e^{-\frac{T_{ON}}{T_a}}}{1 - e^{-T/T_a}} - \frac{e^{T_{ON}/T_a} - 1}{e^{T/T_a} - 1}\right]$$

$$= \frac{V_s}{R_a}\left[\frac{1 - e^{-\frac{T_{ON}}{T_a}}}{1 - e^{-\frac{T}{T_a}}} - \frac{\left(e^{+\frac{T_{ON}}{T_a}} - 1\right)e^{-\frac{T}{T_a}}}{1 - e^{-T/T_a}}\right]$$

$$= \frac{V_s}{R_a}\left[\cancel{\frac{1 - e^{-\frac{T_{ON}}{T_a}} + e^{-T/}}{1 - e^{-T/T_a}}}\right]$$

$$= \frac{V_s}{R_a}\left[\frac{\left(1 - e^{\frac{-T_{ON}}{T_a}}\right) - \left(e^{\frac{T_{ON}}{T_a}} \cdot \bullet - 1\right) e^{-\left(\frac{T_{OFF}+T}{T_a}\right)}}{\left(1 - e^{-T/T_a}\right)}\right.$$

$$= \frac{V_s}{R_a}\left[\frac{1 - e^{-T_{ON}/T_a} - \left(1 - e^{-T_{ON}/T_a}\right) e^{-T_{OFF}/T_a}}{\left(1 - e^{-T/T_a}\right)}\right.$$

$$= \frac{V_s}{R_a} \frac{\left[1 - e^{-T_{ON}/T_a}\right]\left[1 - e^{-T_{OFF}/T_a}\right]}{\left(1 - e^{-T/T_a}\right)}$$

$$= \frac{V_s}{R_a} \frac{\left[1 - e^{-\alpha T/T_a}\right]\left[1 - e^{-(1-\alpha)T/T_a}\right]}{\left[1 - e^{-T/T_a}\right]} \longrightarrow (1)$$

For getting the condition for max. ripple current, differentiate the above eqn. w.r.t α & equate it to zero.

Then we get,

★ $\alpha = 0.5$ (condition for max. ripple current)

$\Rightarrow$ (1) becomes,

$$\Delta I_{max} = \frac{V_s}{R_a} \frac{\left[1 - e^{-0.5T/T_a}\right]\left[1 - e^{-0.5T/T_a}\right]}{\left[1 - e^{-T/T_a}\right]}$$

$$= \frac{V_s}{R_a} \frac{\left(1 - e^{-0.5T/T_a}\right)^2}{\left(1 - \left(e^{-0.5T/T_a}\right)^2\right)}$$

$$= \frac{V_s}{R_a} \frac{\left(1 - e^{-0.5T/T_a}\right)}{\left(1 + e^{-0.5T/T_a}\right)}$$

$$= \frac{V_s}{R_a} \cdot \tanh\left(\frac{T}{4T_a}\right)$$

$$\simeq \frac{V_s}{R_a} \cdot \left(\frac{T}{4T_a}\right)$$

[$\because$ $\tanh x \approx x$ for small value of x]

$$\simeq \frac{V_s}{\cancel{R_a}} \cdot \frac{T}{4 \cdot \frac{L_a}{\cancel{R_a}}}$$

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* $\boxed{(\Delta I)_{max} \simeq \frac{V_s}{4 f L_a}}$

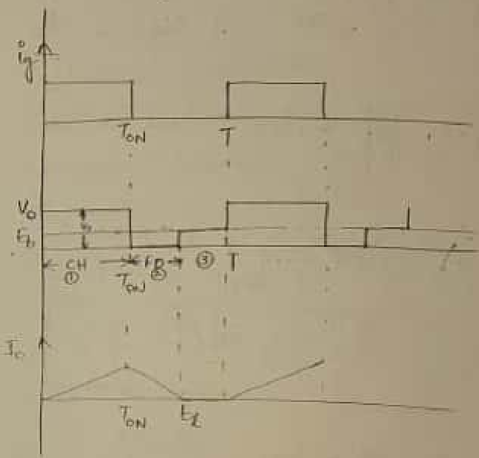
→ The ripple current is inversely proportional to the load inductance & chopping frequency.

→ Thus by increasing the chopping frequency, we can reduce the ripple in the current.

→ Therefore SMPS works based on chopper principle.

→ With the advancement of high switching speed devices like MOSFET, SMPS are popularly used now-a-days for getting very good quality of dc power supply.

(ii) Discontinuous conduction



t_x = Extinction time

→ Extinction time is the time at which inductor releases its complete energy.

$$t_x = T_{ON} + t_a \ln\left[1 + \frac{V_s - E}{E}\left(1 - e^{-T_{on}/T_a}\right)\right]$$

$$V_o = \frac{1}{T}\left[\int_0^{T_{ON}} V_s \cdot dt + \int_{T_{ON}}^{t_x} 0 \cdot dt + \int_{t_x}^{T} E_b \cdot dt\right]$$

$$= \frac{1}{T}\left[V_s \cdot T_{ON} + E_b (T - t_x)\right]$$

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

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

$$V_{or}^2 = \frac{1}{T}\left[\int_0^{T_{ON}} V_s^2 \cdot dt + \int_{t_x}^{T} E_b^2 \cdot dt\right]$$

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

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

Duty cycle limit for continuous conduction:

Let α' be the duty cycle limit for continuous conduction.

(Here α' is the duty cycle at the boundary between continuous & discontinuous conduction)

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

$$= 0$$

$$\Rightarrow \frac{e^{T'_{ON}/T_a} - 1}{e^{T/T_a} - 1} = \frac{E_b}{V_s}$$

Let $\frac{E_b}{V_s} = m$

$$\therefore e^{T'_{ON}/T_a} - 1 = m\left(e^{T/T_a} - 1\right)$$

$$\Rightarrow e^{T'_{ON}/T_a} = 1 + m\left(e^{T/T_a} - 1\right)$$

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

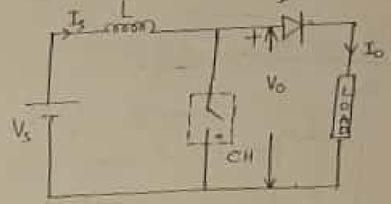
$$\Rightarrow T'_{ON} = T_a \ln\left[1 + m\left(e^{T/T_a} - 1\right)\right]$$

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

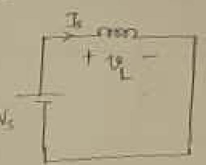
If $\alpha < \alpha'$ $\Rightarrow$ Discontinuous Conduction

$\alpha > \alpha'$ $\Rightarrow$ continuous Conduction

Step up chopper



Mode 1 : 0 to T_{ON}



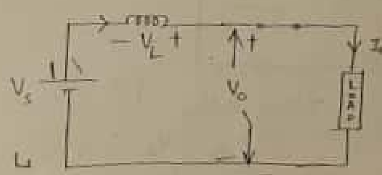
$V_s = V_L$

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

$\int dI_s = \int \frac{V_s}{L} . dt$

$I_s = \frac{V_s}{L} . t + K$ (I_{mn})

Mode 2 :

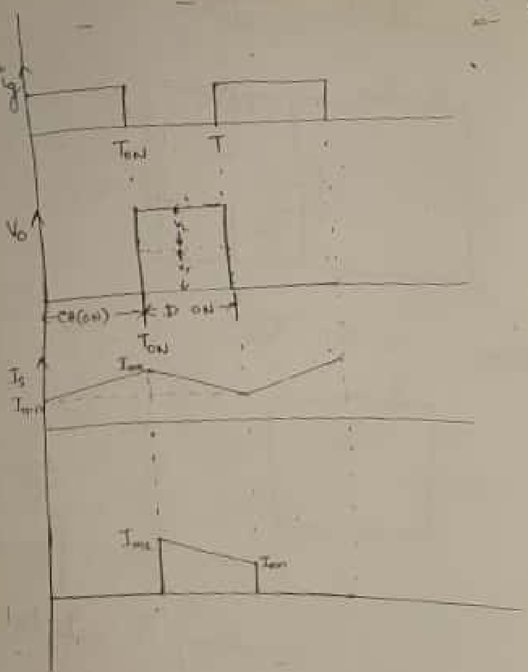


$V_o = V_s + V_L$

L is releasing energy

$I_s = I_o$

$V_L = L\left(\frac{di}{dt}\right)$



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

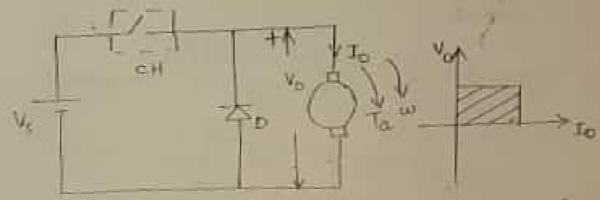
Since $\alpha < 1$,

$V_o > V_s$

→ It is used in Regenerative braking of DC motors.

Chopper fed DC drives

1. First Quadrant chopper (or Type A chopper) stepdown chopper



$V_o = \alpha V_s$

I_o is +ve

⇒ P is +ve i.e, $P_{source} \rightarrow P_{Load}$

Elec → Mech

⇒ F/w Motoring

$V_o = E_b + I_o R_a$

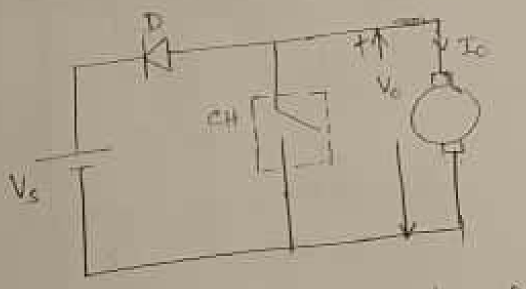
$$\omega = \frac{V_o}{K} - \frac{R_a}{K^2} T_a$$

$K \longrightarrow V \cdot sec/rad$

Nm/A

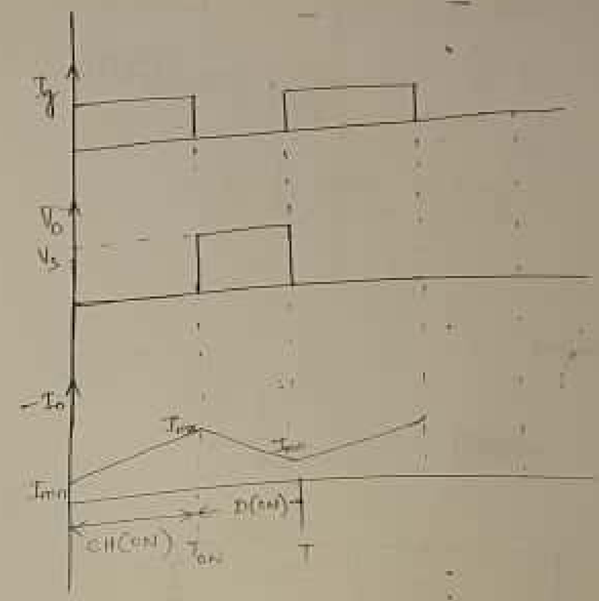
$$\boxed{\cancel{\omega} = \frac{\cancel{\alpha} V_s}{K} - \frac{R_a}{K^2} \cdot T_a}$$

Second Quadrant chopper:
(Type B chopper)

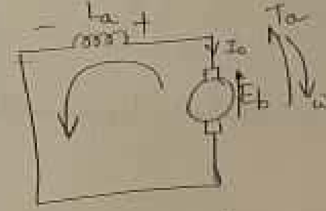


Before $t=0$, the m/c is running at rated speed ω_r

Before $t=0$, M/c energy $= \frac{1}{2} J\omega_r^2$



Mode 1: At $t=0$ sec, chopper is switched ON



$V_0 = 0$

$I_0 = -\frac{E_b}{R_a}$

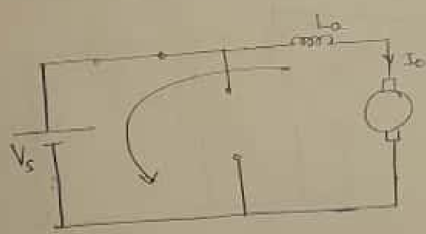
$T_a \propto \phi I_a$

$+ \quad -$

⇒ T_a reverses immediately

$\frac{1}{2} J \omega_r^2 \longrightarrow \frac{1}{2} L_a i_a^2$

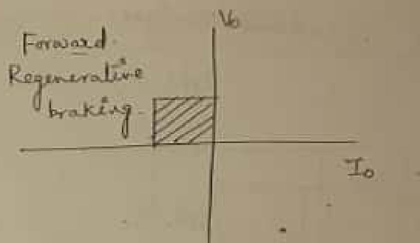
Mode 2:



$\frac{1}{2} L_a i_o^2 \longrightarrow V_s I_o$

P_{source}

Hence, Regenerative braking



$$V_o = \frac{1}{T}\int_{T_{ON}}^{T} V_s \, dt$$

$$= \frac{T - T_{ON}}{T} \cdot V_s$$

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

$$\Rightarrow V_s > V_o$$

→ This alone can't be used in practical applications

i.e., It is not stand alone chopper.

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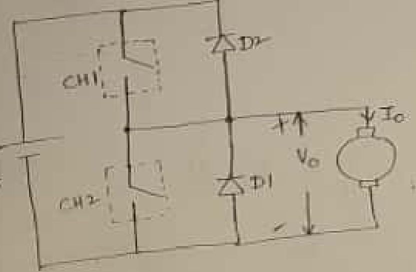
Two Quadrant chopper
(Type c)



CH2 → operating (α_2)

① $CH_2 \rightarrow ON \Rightarrow \frac{1}{2}J\omega^2 \rightarrow \frac{1}{2}Li^2$

② $CH_2 \rightarrow OFF \Rightarrow D_2$ ON

$\rightarrow \frac{1}{2}Li^2 \rightarrow P_{source}$

CH1 → operating (α_1)

① $CH_1 \rightarrow ON$; $V_0 = V_s$

② $CH_1 \rightarrow OFF$

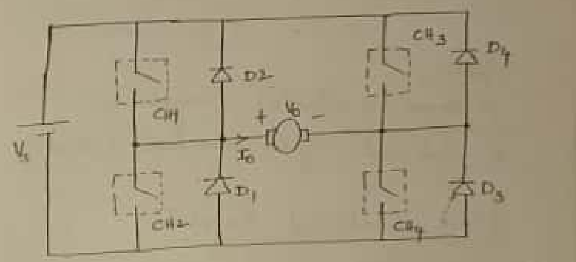
$D_1 \rightarrow ON$ (FWP)

$V_0 = E_b + I_0R_a$

$V_0 = \alpha_1 V_s$

V_0 / I_0

Four Quadrant chopper



Fwd Reg braking P(-ve)
$CH_2(\alpha_2)$

① CH_2 ON ⇒ D3 also ON
⇒ $V_0 = 0$; $I_0 = -\frac{E_b}{R_a}$; T -ve
$\frac{1}{2}J\omega^2 \rightarrow \frac{1}{2}Li^2$

② CH_2 OFF ⇒ D_2 & D_3 ON ⇒ $\frac{1}{2}Li^2 +$ ...

P (+ve)
CH_1 → operated (α_1)
CH_4 → continuosly ON

mode ① CH_1, CH_4 ON ⇒ V_0 +ve ; I_0 +ve
mode ② $CH_1 \rightarrow OFF \Rightarrow D_1$ & CH_4 (FWP)
FWD Motoring ; $V_0 = \alpha_1 V_s$

V_0 / I_0

CH_3 is operating (α_3) P (+ve)
CH_2 is continuosly ON
Mode1: $CH_3 - CH_2$ ON ⇒ $V_0 = -V_s$, I_0 is -ve
Mode2: CH_3 OFF ⇒ $CH_2 - D_3$ ON (FWP)
Rev Motoring

CH_4 is operating (α_4)
Mode1: $CH_4 - D_1$ ON ⇒ I_0 +ve ⇒ T +ve
$\frac{1}{2}J\omega^2 \rightarrow \frac{1}{2}Li^2$
Mode2: CH_4 OFF
Immediately $D_1 D_4$ become ON
$\frac{1}{2}Li^2 \rightarrow P_{source}$
Rev-Rg braking

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