5/12/19

# UNIT-2

## CONTROL CONVERTER FED DC MOTOR DRIVES.

Discussed topics:-

→ Single phase semicontrol fed DC seperately excited motor.

→ Single phase fully controled fed DC sepe-rately excited motor.

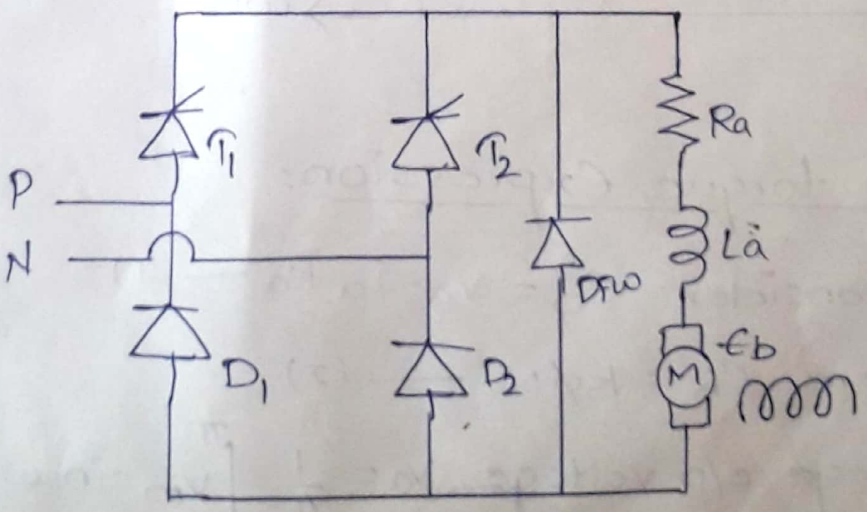
→ 1-ϕ semi control fed DC series motor

→ 1-ϕ fully controlled fed DC. Series. motor

→ Principle & Operation of Dual Converter & Dual convert of a DC motor.

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### * 1-ϕ semi controlled fed DC seperately excited motor:

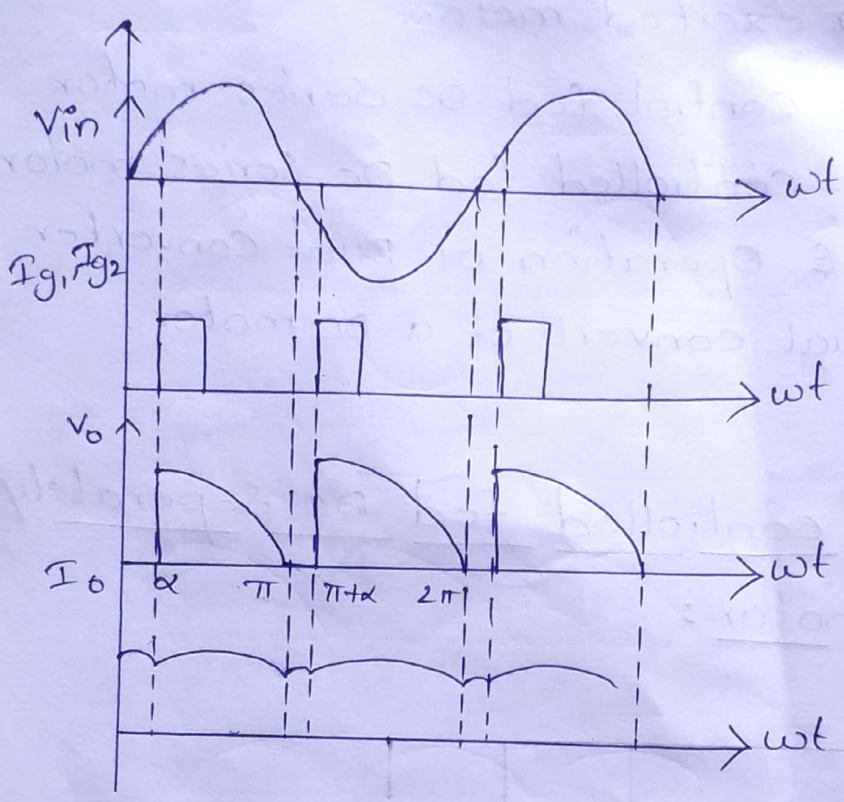




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(i) continous mode :-

| Conduction Period | Switches | Current path | o/p voltage. |
|---|---|---|---|
| $\alpha - \pi$ | $T_1, D_1$ | $P \to T_1 \to M \to D_1 \to N$ | $V_s$ |
| $\pi \to \pi+\alpha$ | $T_1, D_2$ (or) DFW | DFW | 0 |
| $\pi+\alpha \to 2\pi$ | $T_2, D_2$ | $N \to T_2 \to M \to D_2 \to P$ | $V_s$ |




## Speed torque Expression:

Consider $\epsilon_b = V_a - I_a R_a$ — (1)

Here $\epsilon_b = K\phi N$ — (2)

ararege o/p voltage $V_a = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin \omega t \, d(\omega t)$

$= \frac{V_m}{\pi}\left[-\cos \omega t\right]_{\alpha}^{\pi}$

$= \frac{V_m}{\pi}(1+\cos\alpha)$


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$$V_a = \frac{V_m}{\pi}(1+\cos\alpha) \quad \text{— (3)}$$

Sub (2) & (3) in (1)

$$\epsilon_b = V_a - I_a R_a$$

$$K\phi N = \frac{V_m}{\pi}(1+\cos\alpha) - I_a R_a$$

$$N = \frac{\frac{V_m}{\pi}(1+\cos\alpha) - I_a R_a}{K\phi} \quad \text{— (4)}$$

Here, $T \propto \phi I_a$

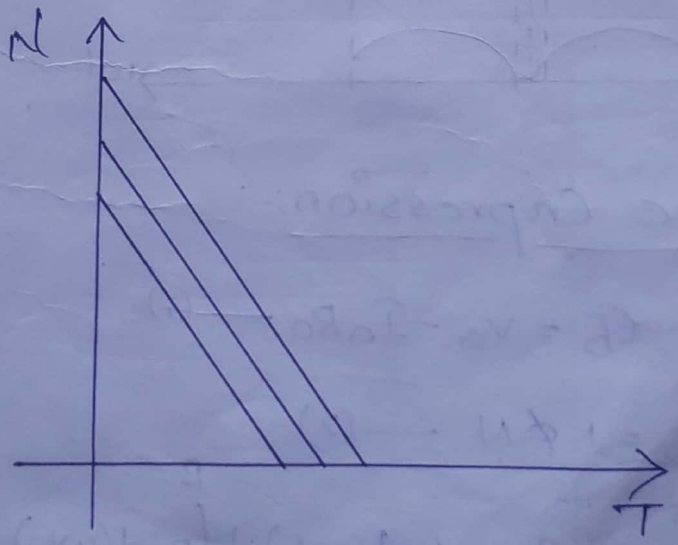
$$T = K\phi I_a$$

then $I_a = \frac{T}{K\phi}$ — (5)

Sub (5) in (4)

$$N = \frac{\frac{V_m}{\pi}(1+\cos\alpha)}{K\phi} - \frac{T \cdot R_a}{(K\phi)^2}$$

## N & T characteristic :-

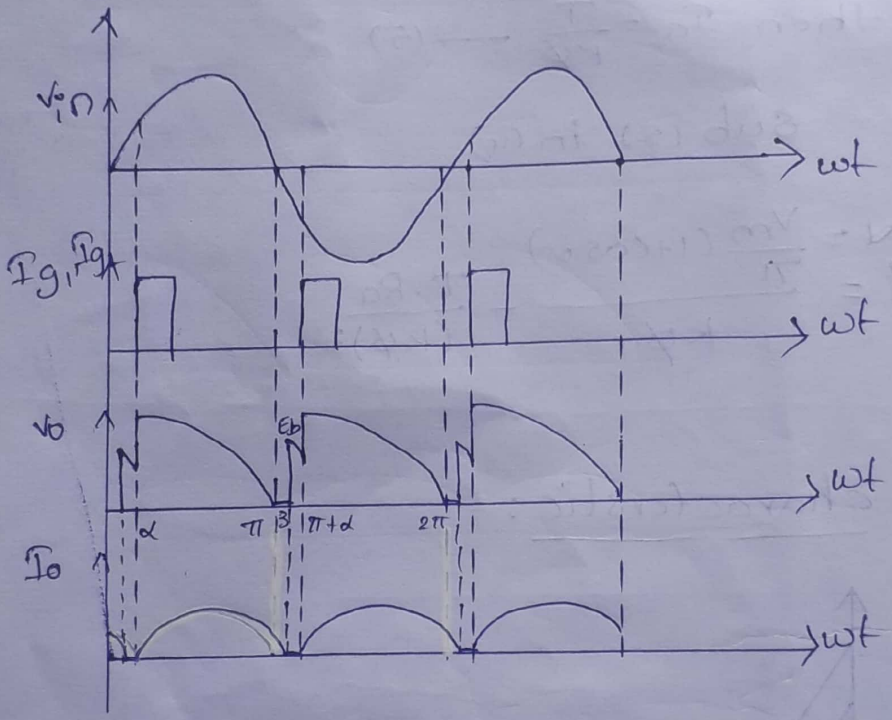




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## (ii) Discontinous mode:-

| Conduction Period | Switches | Current path | o/p voltage |
|---|---|---|---|
| $\alpha - \pi$ | $T_1, D_1$ | $P \to T_1 \to M \to D_1 \to N$ | $V_s$ |
| $\pi \to \beta$ | $T_1, D_2$ (or) $D_{FW}$ | DFW | 0 |
| $\beta \to \pi + \alpha$ | motor | - | $\epsilon_b$ |
| $\pi + \alpha \to 2\pi$ | $T_2, D_2$ | $N \to T_2 \to M \to D_2 \to P$ | $V_s$ |




## Speed torque expression:-

Consider $\epsilon_b = V_a - I_a R_a$ —(1)

Here $\epsilon_b = K\phi N$ —(2)

$$V_a = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, d(\omega t) + \int_{\pi}^{\beta} 0 \cdot d(\omega t) + \int_{\beta}^{\pi+\alpha} \epsilon_b \cdot d(\omega t)$$

$$V_a = \frac{V_m}{\pi}(1+\cos\alpha) + \epsilon_b(\pi + \alpha - \beta) \quad —(3)$$


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Sub (2) & (3) in (1)

$$E_b = V_a - I_a R_a$$

$$K\phi N = \frac{V_m}{\pi}(1+\cos\alpha) + E_b(\pi+\alpha-\beta) - I_a R_a$$

$$N = \frac{\frac{V_m}{\pi}(1+\cos\alpha) + E_b(\pi+\alpha-\beta) - I_a R_a}{K\phi} \quad \text{---(4)}$$

Here $T \propto \phi I_a$

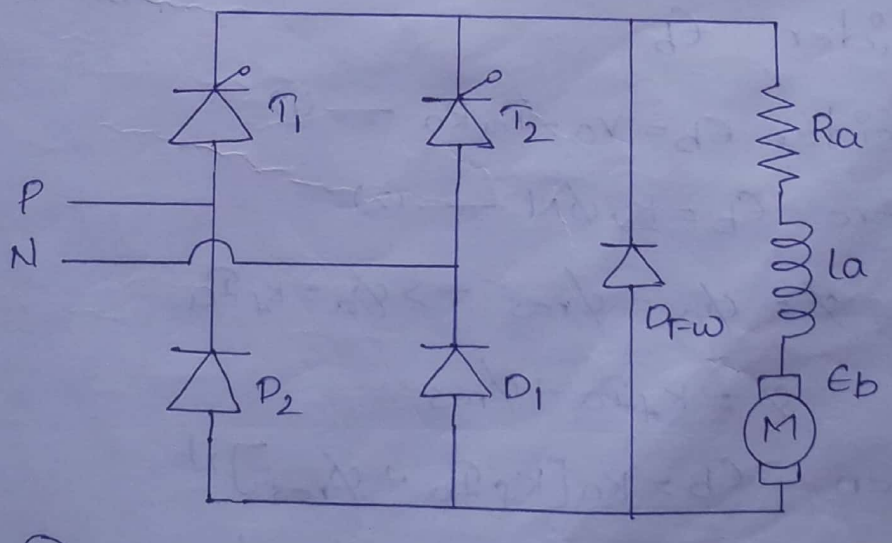
$T = K\phi I_a$

then $I_a = \frac{T}{K\phi}$ ---(5)

Sub (5) in (4)

$$N = \frac{\frac{V_m}{\pi}(1+\cos\alpha) + E_b(\pi+\alpha-\beta) - I_a R_g}{K\phi} - \frac{I_a R_g}{(K\phi)^2}$$

## * 1-$\phi$ Semi control DC series motor:-



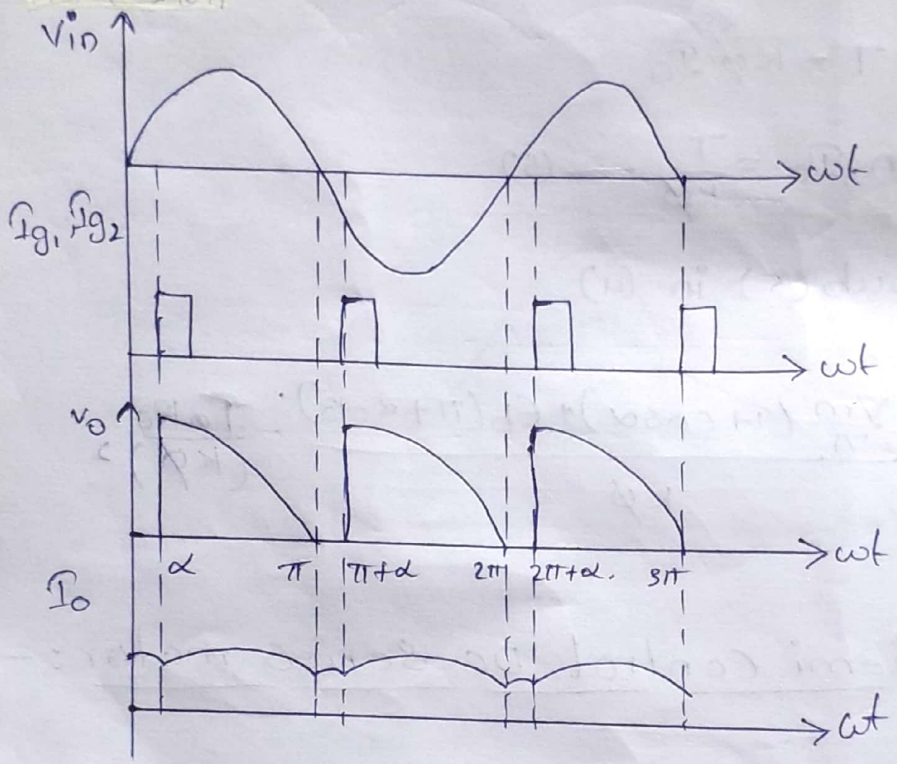




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## (i) Continous mode :-

| Conduction Period | Switches | Current path | o/p voltage. |
|---|---|---|---|
| +ve<br>$\alpha \to \pi$ | $T_1, D_1$ | $P \to T_1 \to M \to D_1 \to N$ | $V_s$ |
| $\pi \to \pi+\alpha$ | $T_1, D_2$ (or) $D_{FW}$ | $D_{FW}$ | 0 |
| -ve<br>$\pi+\alpha \to 2\pi$ | $T_2, D_2$ | $N \to T_2 \to M \to D_2 \to P$ | $V_s$ |




Consider $\epsilon_b$

Consider $\epsilon_b = V_a - I_a R_a$ — (1)

Here $\epsilon_b = K_a \phi N$ — (2)

$\phi = \phi_a = \phi_{res} \Rightarrow \phi_a = K_f I_a$

$\phi = K_f I_a + \phi_{res}$

then $\epsilon_b = K_a [K_f I_a + \phi_{res}] N$

$\epsilon_b = K_{af} I_a N + K \phi_{res} N$

$\epsilon_b = K_{af} I_a N + K_{res} N$


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$$\epsilon_b = [K_{af} I_a + K_{res}] N \quad \text{---(3)}$$

$$V_a = \frac{1}{\pi} \int_a^{\pi} V_m \sin\omega t \, d(\omega t)$$

$$= \frac{V_m}{\pi} (1+\cos\alpha) \quad \text{---(4)}$$

sub (3) & (4) in (1)

$$\epsilon_b = V_a - I_a R_a$$

$$[K_{af} I_a + K_{res}] N = \frac{V_m}{\pi} (1+\cos\alpha) - I_a R_a$$

$$N = \frac{V_m/\pi (1+\cos\alpha) - I_a R_a}{K_{af} I_a + K_{res}}$$

$$K_{af} I_a N + K_{res} N = V_m/\pi (1+\cos\alpha) - I_a R_a$$

$$K_{af} I_a N + I_a R_a = V_m/\pi (1+\cos\alpha) - K_{res} N$$

$$I_a [K_{af} N + R_a] = V_m/\pi (1+\cos\alpha) - K_{res} N$$

$$I_a = \frac{V_m/\pi (1+\cos\alpha) - K_{res} N}{K_{af} N + R_a}$$

$T \propto \phi I_a \Rightarrow T = K \phi I_a$

$\phi \propto I_a$ then $T = K_a I_a^2$

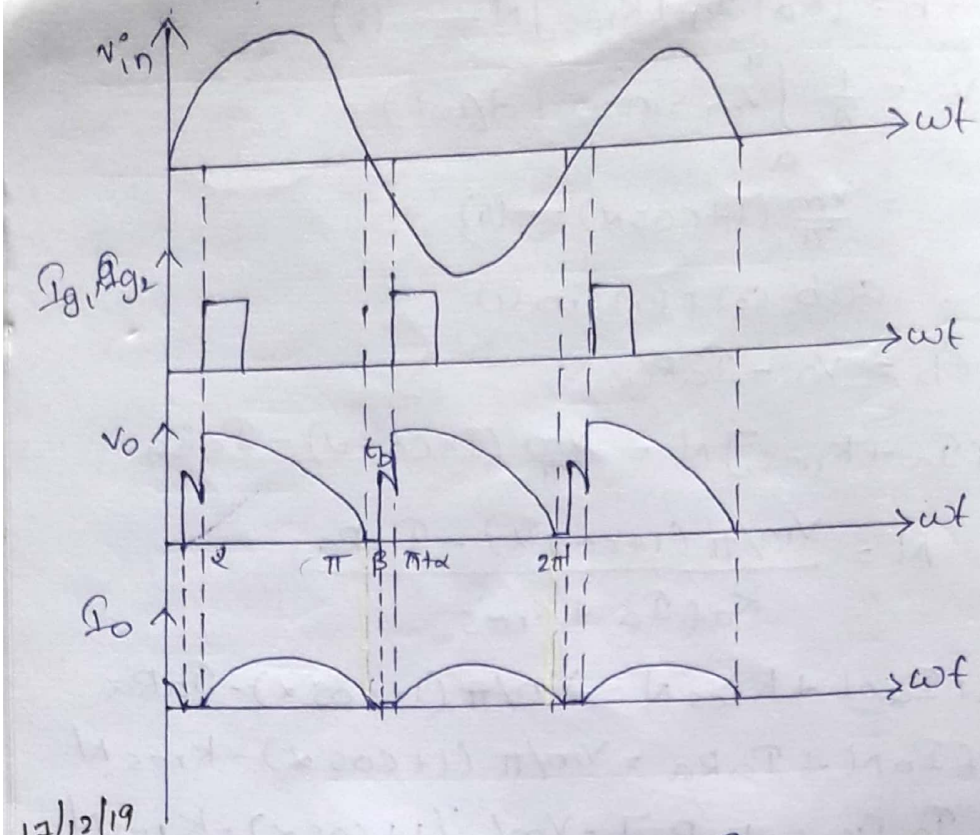
$$T = K_a \left[ \frac{\frac{V_m}{\pi}(1+\cos\alpha) - K_{re}N}{K_{af} N + R_a} \right]^2$$

(ii) Discontinous mode:

| Conduction period | Switches | current path | o/p voltage |
|---|---|---|---|
| $\alpha - \pi$ | $T_1, D_1$ | $P \to T_1 \to M \to D_1 \to N$ | $V_s$ |
| $\pi - \beta$ | $T_1, D_2$ (or) $D_{fw}$ | $D_{fw}$ | 0 |
| $\beta \to \pi + \alpha$ | motor | - | $\epsilon_b$ |
| $\pi + \alpha \to 2\pi$ | $T_2, D_2$ | $N \to T_2 \to M \to D_2 \to P$ | $V_s$ |




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## Speed torque expression:

Consider $\epsilon_b = V_a - I_a R_a$ — (1)

Here $\epsilon_b = K_a \phi N$ — (2)

$\phi = \phi_a + \phi_{res}$ $\quad \phi \propto I_a$

$\phi_a = K_f I_a$

$\phi = K_f I_a + \phi_{res}$ — (3)

Sub (3) in (2)

$\epsilon_b = K_a (K_f I_a + \phi_{res}) N$

$\epsilon_b = K_a K_f I_a N + K_a \phi_{res} N$

$\epsilon_b = K_{af} I_a N + K_{res} N$ — (3)

$\epsilon_b = (K_{af} I_a + K_{res}) N$ — (4)

Average o/p voltage

$$V_a = \frac{1}{\pi} \int_{\alpha}^{\beta} V_m \sin \omega t \, d(\omega t) + \int_{\beta}^{\pi+\alpha} \epsilon_b \, d(\omega t)$$


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$$= \frac{V_m}{\pi}[\cos\alpha - \cos\beta] + \epsilon_b[\pi + \alpha - \beta] \quad \text{---(5)}$$

Sub (4) & (5) in (1)

$$\epsilon_b = V_a - I_a R_a$$

$$(K_{af} I_a + K_{res})N = \frac{V_m}{\pi}[\cos\alpha - \cos\beta] + \epsilon_b(\pi + \alpha - \beta) - I_a R_a$$

$$N = \frac{\frac{V_m}{\pi}[\cos\alpha - \cos\beta] + \epsilon_b(\pi + \alpha - \beta) - I_a R_a}{K_{af} I_a + K_{res}}$$

from above eqn calculate $I_a$

$$K_{af} I_a N + K_{res} = \frac{V_m}{\pi}[\cos\alpha - \cos\beta] + \epsilon_b(\pi + \alpha - \beta) - I_a R_a$$

$$K_{af} I_a N + I_a R_a = \frac{V_m}{\pi}[\cos\alpha - \cos\beta] + \epsilon_b[\pi + \alpha - \beta] - K_{res} N$$

$$I_a[K_{af} N + R_a] = \frac{V_m}{\pi}[\cos\alpha - \cos\beta] + \epsilon_b(\pi + \alpha - \beta) - K_{res} N$$

$$I_a = \frac{\frac{V_m}{\pi}[\cos\alpha - \cos\beta] + \epsilon_b(\pi + \alpha - \beta) - K_{res} N}{K_{af} N + R_a}$$

we known in series motor

$$T \propto I_a^2$$

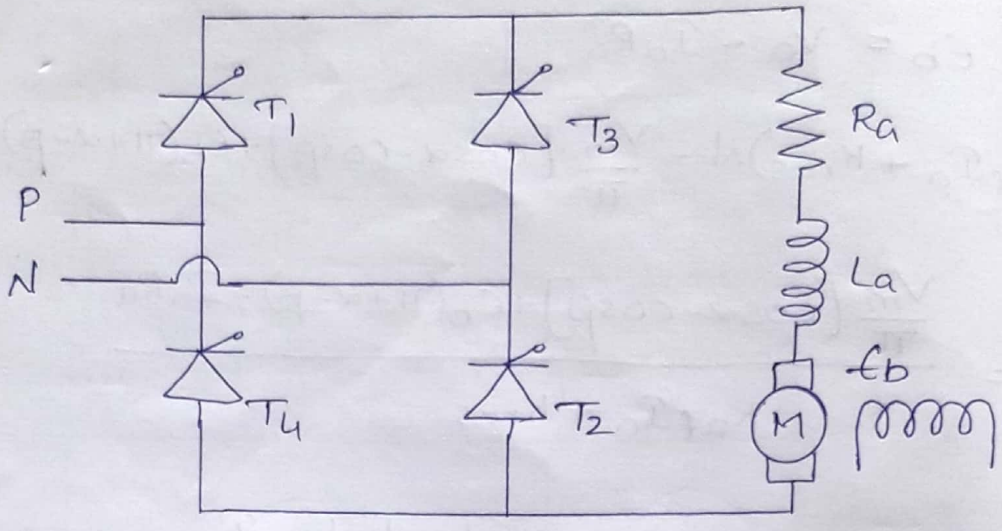
$$T = K_a I_a^2$$

$$T = K_a \left[\frac{\frac{V_m}{\pi}[\cos\alpha - \cos\beta] + \epsilon_b(\pi + \alpha - \beta) - K_{res} N}{K_{af} N + R_a}\right]^2$$



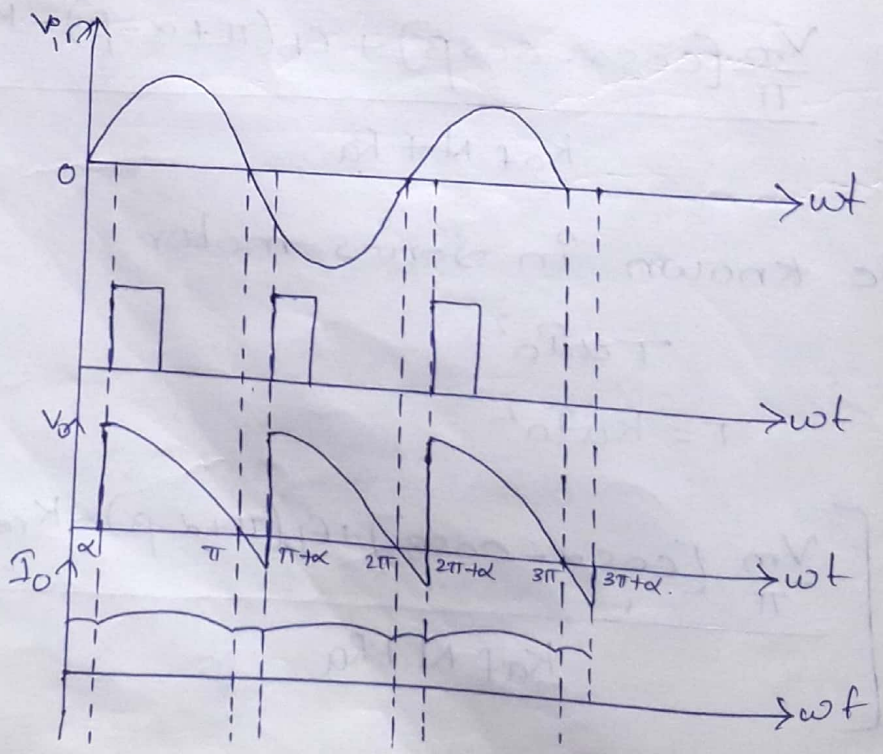

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# * 1-ϕ fully controlled Seperately excited Dc Series motor:-




## (i) Continous mode:-

| Conduction Period | Switches | Current path | o/p voltage. |
|---|---|---|---|
| $\alpha \to \pi$ | $T_1, T_2$ | $P \to T_1 \to M \to T_2 \to N$ | $V_s$ |
| $\pi \to \pi+\alpha$ | $T_3, T_4$ | $N \to T_3 \to M \to T_4 \to P$ | $V_s$ |





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## Speed & Torque Expression :-

Consider

$$\epsilon_b = V_a - I_a R_a \quad \text{---(1)}$$

Here, $\epsilon_b = K\phi N$ ---(2)

Avarage o/p voltage

$$V_a = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \, d(\omega t)$$

$$= \frac{V_m}{\pi}\left[-\cos(\pi+\alpha)+\cos\alpha\right]$$

$$V_a = \frac{2V_m}{\pi}(\cos\alpha) \quad \text{---(3)}$$

Sub (2) & (3) in (1)

$$\epsilon_b = V_a - I_a R_a$$

$$K\phi N = \frac{2V_m}{\pi}\cos\alpha - I_a R_a$$

$$N = \frac{\frac{2V_m}{\pi}\cos\alpha}{K\phi} - \frac{I_a R_a}{K\phi} \quad \text{---(4)}$$

In separately excited motor

$$T \propto \phi I_a$$

$$T = K\phi I_a$$

$$I_a = \frac{T}{K\phi} \quad \text{---(5)}$$

Sub (5) in (4)

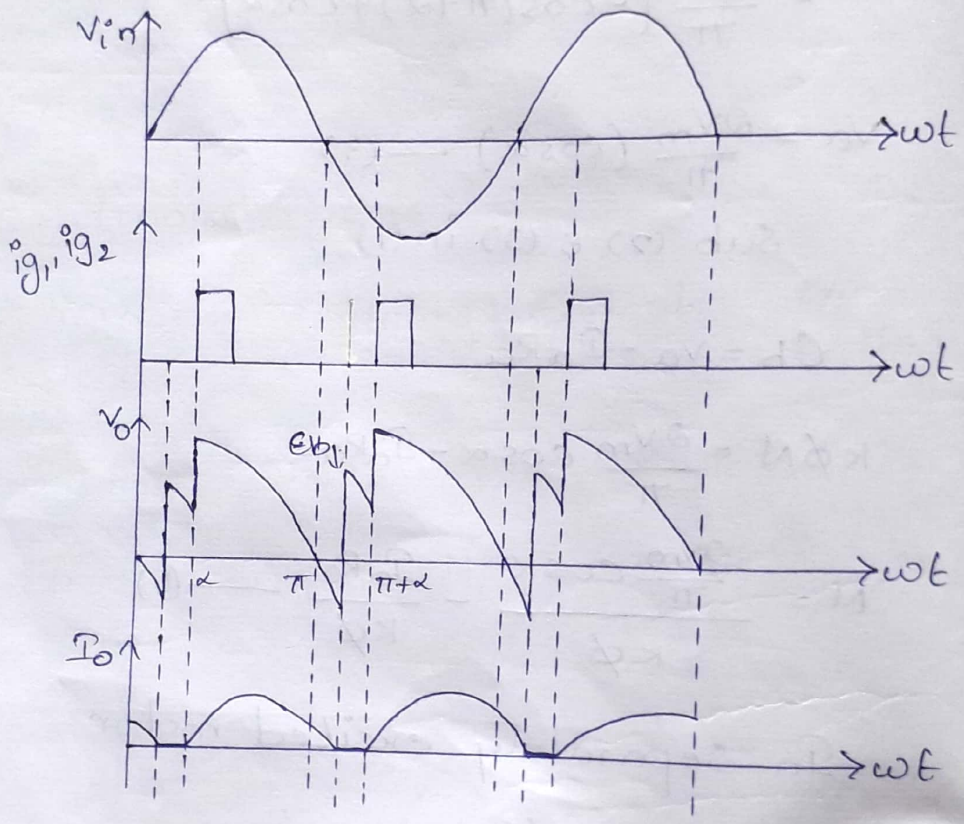
$$N = \frac{\frac{2V_m}{\pi}\cos\alpha}{K\phi} - \frac{TR_a}{(K\phi)^2}$$


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## * (ii) Discontinous mode:-

| Conduction Period | Switches | Current path | o/p voltage |
|---|---|---|---|
| $\alpha \rightarrow \beta$ | $T_1, T_2$ | $P \rightarrow T_1 \rightarrow M \rightarrow T_2 \rightarrow N$ | $V_s$ |
| $\beta \rightarrow \pi+\alpha$ | $T_1, T_4$ (or) $T_3, T_2$ | motor | $\epsilon_b$ |
| $\pi+\alpha \rightarrow 2\pi$ | $T_3, T_4$ | $N \rightarrow T_3 \rightarrow M \rightarrow T_4 \rightarrow P$ | $V_s$ |




### Speed & Torque Expression.

$$\epsilon_b = V_a - I_a R_a \quad \text{— (1)}$$

Here, $\epsilon_b = K\phi N$ — (2)

Avarage o/p voltage

$$V_a = \frac{1}{\pi}\int_{\alpha}^{\beta} V_m \sin\omega t \, d(\omega t) + \int_{\beta}^{\pi+\alpha} \epsilon_b \, d(\omega t)$$


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$$= \frac{V_m}{\pi}(\cos\alpha - \cos\beta) + \epsilon_b(\pi + \alpha - \beta) \quad \text{---(3)}$$

sub (3) & (2) in (1)

$$\epsilon_b = V_a - I_a R_a$$

$$K\phi N = \frac{V_m}{\pi}(\cos\alpha - \cos\beta) + \epsilon_b(\pi + \alpha - \beta) - I_a R_a$$

$$N = \frac{\frac{V_m}{\pi}(\cos\alpha - \cos\beta) + \epsilon_b(\pi + \alpha - \beta)}{K\phi} - \frac{I_a R_a}{K\phi} \quad \text{---(4)}$$

In seperatly excited DC Motor.

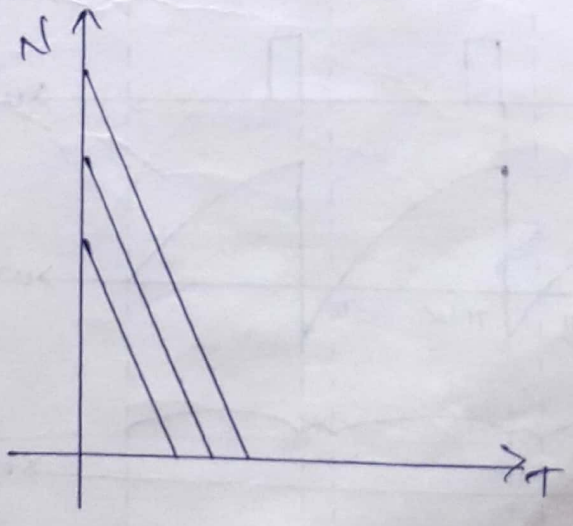
$$T \propto \phi I_a \Rightarrow T = K\phi I_a$$

$$I_a = \frac{T}{K\phi} \quad \text{---(5)}$$

sub (5) in (4)

$$N = \frac{\frac{V_m}{\pi}(\cos\alpha - \cos\beta) + \epsilon_b(\pi + \alpha - \beta)}{K\phi} - \frac{TR_a}{(K\phi)^2}$$

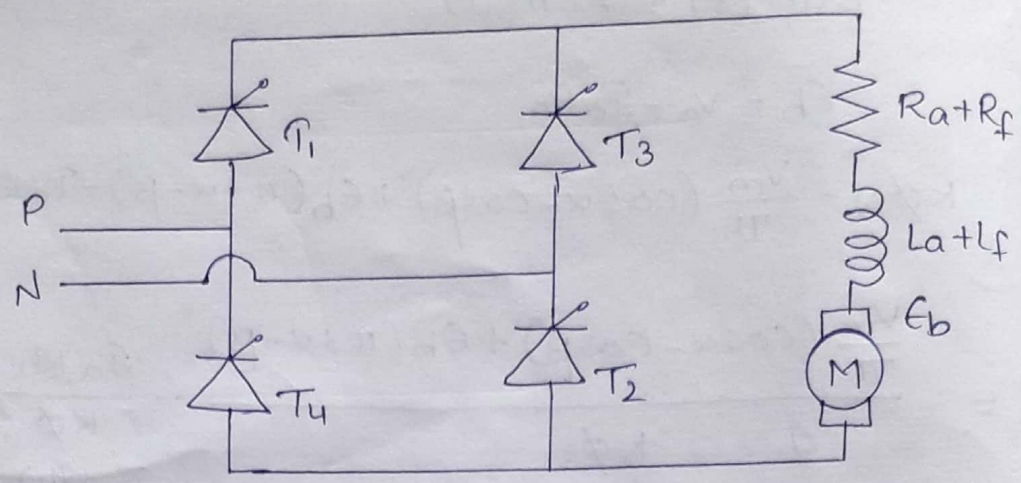
N & T characterstics:-





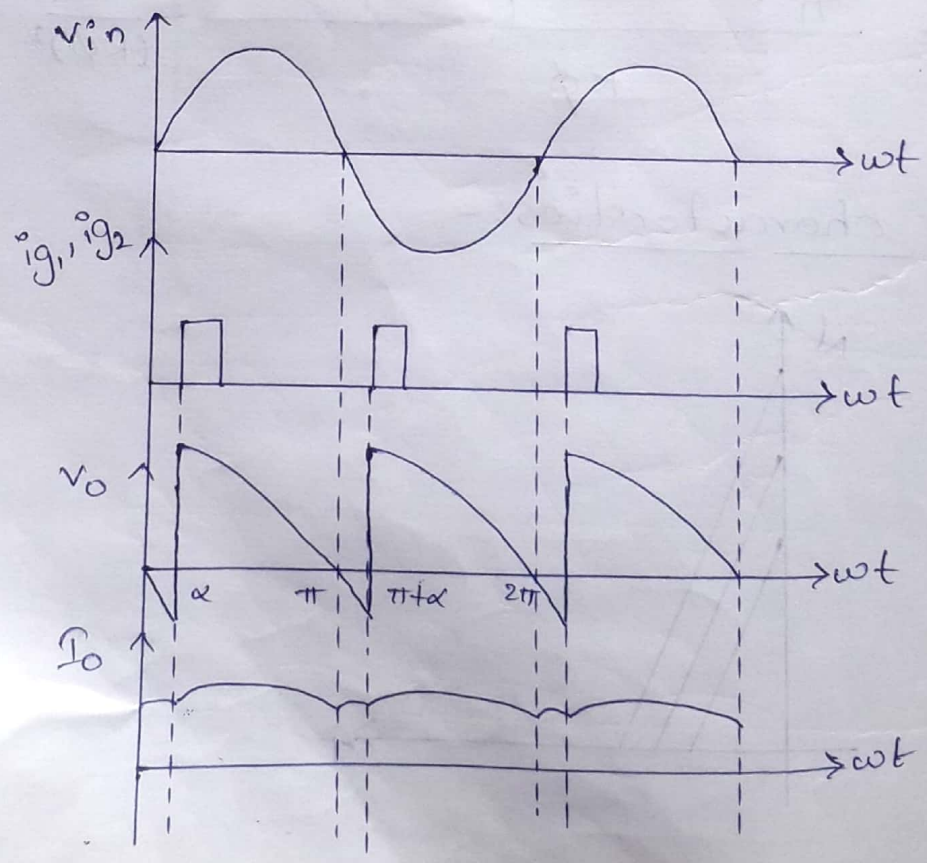
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## * 1-ϕ fully controlled DC Series motor:-




### (i) Continous Mode:-

| Conduction period | Switches | Current path | O/P voltage |
|---|---|---|---|
| $\alpha \rightarrow \pi+\alpha$ | $T_1, T_2$ | $P \rightarrow T_1 \rightarrow M \rightarrow T_2 \rightarrow N$ | $V_s$ |
| $\pi+\alpha \rightarrow 2\pi$ | $T_3, T_4$ | $N \rightarrow T_3 \rightarrow M \rightarrow T_4 \rightarrow N$ | $V_s$ |





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## Speed & Torque Expression:

$$\epsilon_b = V_a - I_a R_a \quad \text{---(1)}$$

Here,

$$\epsilon_b = K\phi N \quad \text{---(2)}$$

In series motor

$$\phi = \phi_a + \phi_{res}$$

$$\phi_a \propto I_a \Rightarrow \phi_a = K_f I_a$$

$$\phi = K_f I_a + \phi_{res} \quad \text{---(3)}$$

Sub (3) in (2)

$$\epsilon_b = K(K_f I_a + \phi_{res}) N$$

$$\epsilon_b = K_{af} I_a N + K_{res} N \quad \text{---(4)}$$

average o/p voltage

$$V_a = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin \omega t \, d(\omega t) = \frac{2V_m}{\pi}\cos\alpha \quad \text{---(5)}$$

Sub (4) & (5) in (1)

$$\epsilon_b = V_a - I_a R_a$$

$$K_{af} I_a N + K_{res} N = \frac{2V_m}{\pi}\cos\alpha - I_a R_a$$

$$K_{af} I_a N + I_a R_a = \frac{2V_m}{\pi}\cos\alpha - K_{res} N$$

$$I_a = \frac{\frac{2V_m}{\pi}\cos\alpha - K_{res} N}{K_{af} N + R_a} \quad \text{---(6)}$$

In Serics motor




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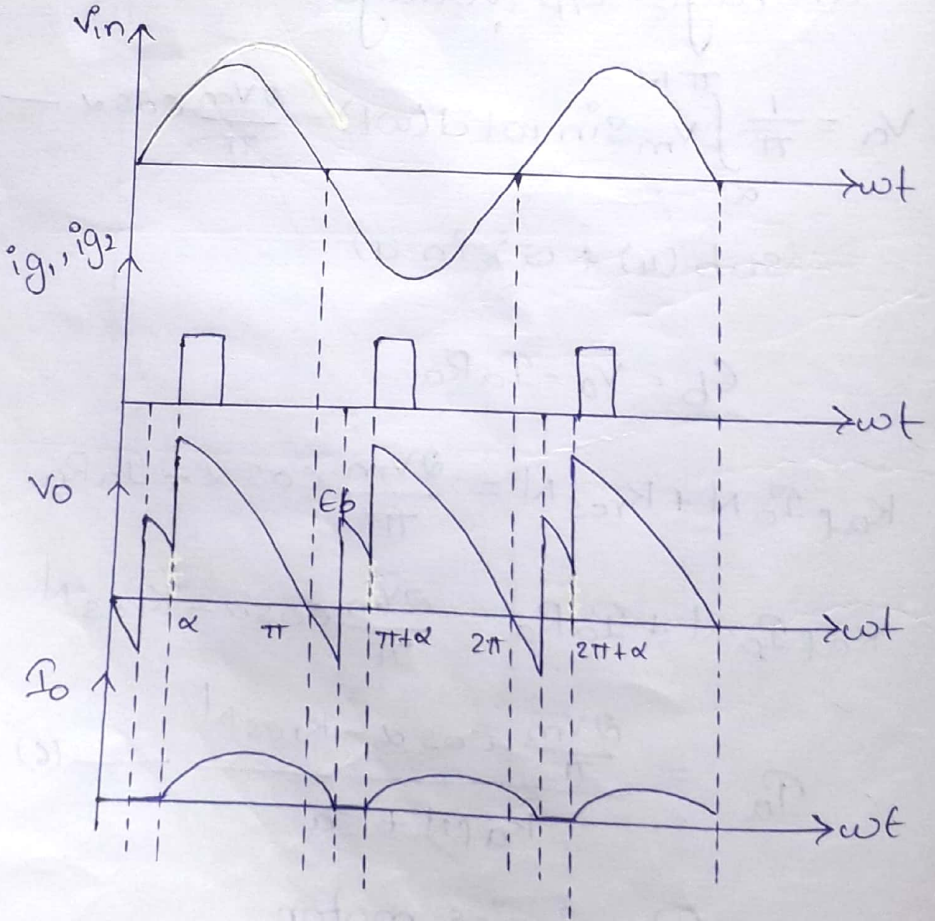
$$T \propto I_a^2$$

$$T = K I_a^2$$

$$T = K\left[\frac{\frac{2V_m}{\pi}\cos\alpha - K_{rcs}N}{K_{af}N + R_a}\right]^2$$

## (ii) Discontinous Mode:-

| Conduction Period | Switches | Current path | O/P voltage |
|---|---|---|---|
| $\alpha - \beta$ | $T_1, T_2$ | $P \to T_1 \to M \to T_2 \to N$ | $V_s$ |
| $\beta \to \pi+\alpha$ | $T_1, T_4$ (or) $T_3, T_2$ | motor | $E_b$ |
| $\pi+\alpha \to 2\pi$ | $T_3, T_4$ | $N \to T_3 \to M \to T_4 \to P$ | $V_s$ |





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## Speed & Torque Expression.

$$\epsilon_b = V_a - I_a R_a \quad \text{—— (1)}$$

Here, $\epsilon_b = K\phi N$ —— (2)

In series motor

$$\phi = \phi_a + \phi_{res}$$

$$\phi_a \propto I_a \Rightarrow \phi_a = K_f I_a$$

$$\phi = K_f I_a + \phi_{res} \quad \text{—— (3)}$$

Sub (3) in (2)

$$\epsilon_b = K(K_f I_a + \phi_{res})N$$

$$\epsilon_b = K_{af} I_a N + K_{res} N \quad \text{—— (4)}$$

Average o/p voltage

$$V_a = \frac{1}{\pi}\int_{\alpha}^{\beta} V_m \sin\omega t \, d(\omega t) + \int_{\beta}^{\pi+\alpha} \epsilon_b \, d(\omega t)$$

$$= \frac{V_m}{\pi}(\cos\alpha - \cos\beta) + \epsilon_b(\pi + \alpha - \beta) \quad \text{—— (5)}$$

Sub (4) & (5) in (1)

$$\epsilon_b = V_a - I_a R_a$$

$$K_{af} I_a N + K_{res} N = \frac{V_m}{\pi}(\cos\alpha - \cos\beta) + \epsilon_b(\pi + \alpha - \beta) - I_a R_a$$

$$K_{af} I_a N + I_a R_a = \frac{V_m}{\pi}(\cos\alpha - \cos\beta) + \epsilon_b(\pi + \alpha - \beta) - K_{res} N$$




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$$I_a = \frac{\frac{V_m}{\pi}(\cos\alpha - \cos\beta) + E_b(\pi + \alpha - \beta) - K_{res}N}{K_{af}N + R_a}$$

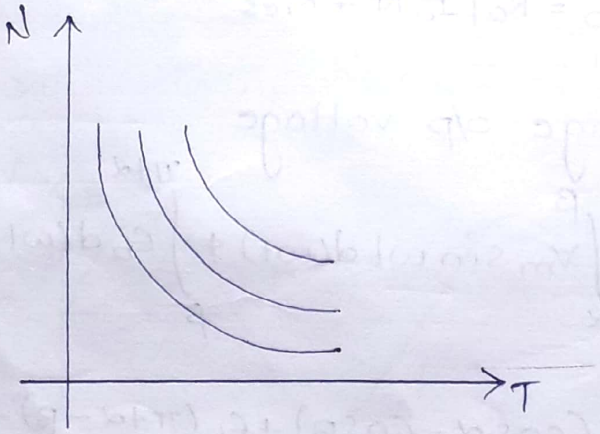
In series motor

$$T \propto I_a^2$$

$$T = K I_a^2$$

$$T = K\left[\frac{\frac{V_m}{\pi}(\cos\alpha - \cos\beta) + E_b(\pi + \alpha - \beta) - K_{res}N}{K_{af}N + R_a}\right]^2$$

N & T characteristics:-




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* Dual converter:-

→ Dual convertor is combination of two full converters connected in anti parallel

→ 1-ϕ a semi control convertor satisfy 1st quadrant operation.

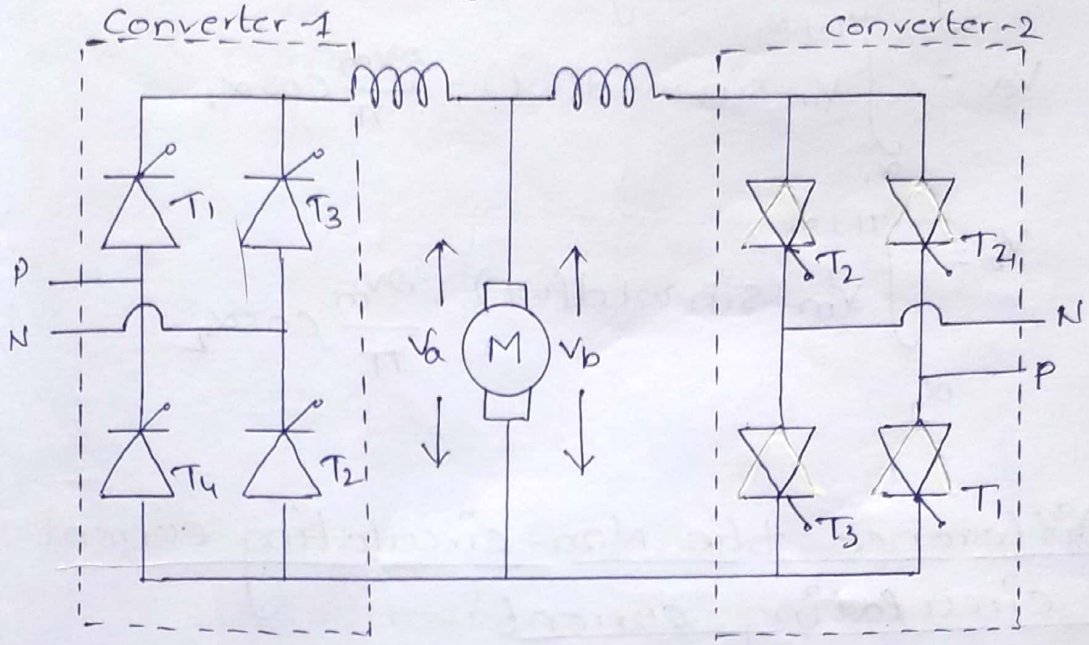
→ 1-ϕ fully control convertor satisfy two quadrant operation, but dual converter

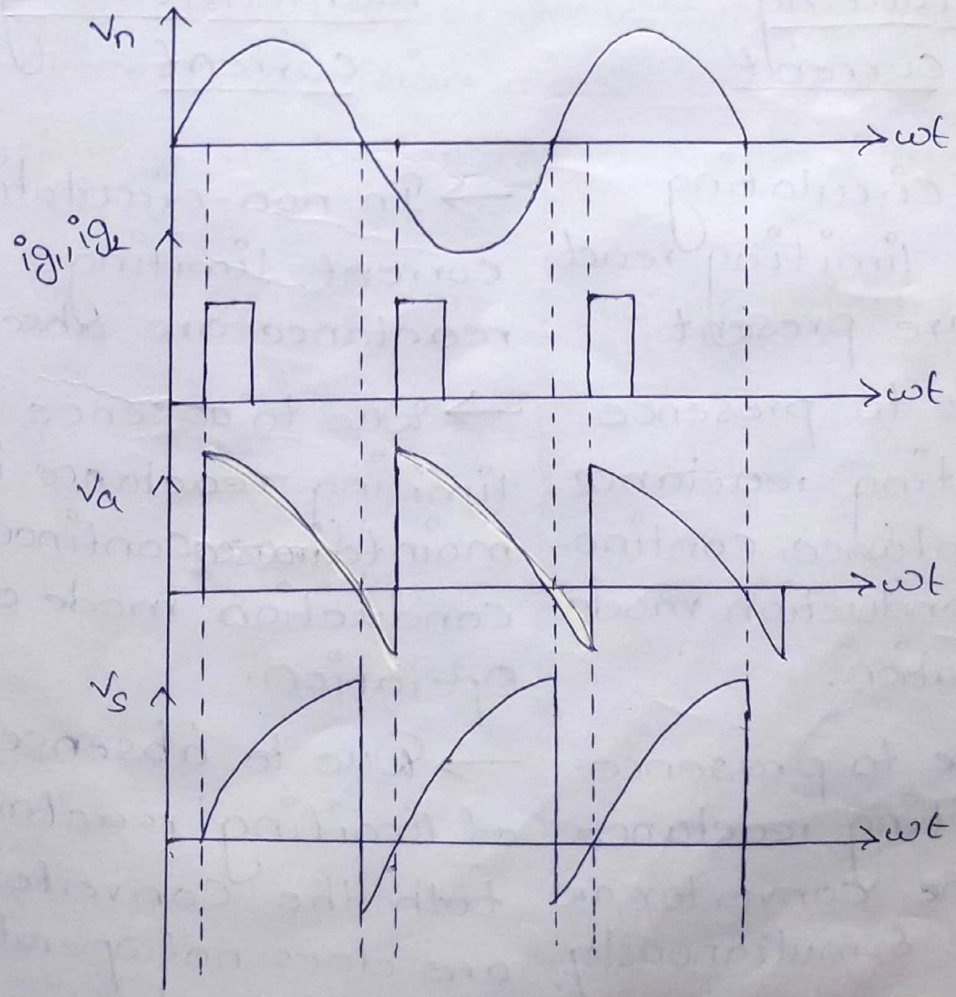

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satisfy 4 quadrant operation of DC drive.

→ Dual convertor classified into 2 types.

* Non-circulating current
* Circulating current.





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In Dual converter.

$\alpha_1 + \alpha_2 = 180^\circ$

$\alpha_1 < 90^\circ, \alpha_2 > 90^\circ$

average o/p voltage

$$V_a = \int_{\alpha_1}^{\pi+\alpha_1} V_m \sin \omega t \, d(\omega t) = \frac{2V_m}{\pi} \cos \alpha_1$$

$$V_b = \int_{\alpha_2}^{\pi+\alpha_2} V_m \sin \omega t \, d(\omega t) = \frac{2V_m}{\pi} \cos \alpha_2$$

## * Difference b/w Non-circulating current and circulating current :-

| Circulating current | Non-circulating current. |
|---|---|
| → In circulating current limiting reactance are present. | → In non-circulating current limiting reactance are absent |
| → Due to presence of limiting reactance it maintance continuous conduction mode of operation. | → Due to absence of limiting reactance it maintance continous conduction mode of operation. |
| → Due to presence of limiting reactance both the convertor are operate simultanously. | → Due to absence of limiting reactance both the convertor are does not operate simultanously. |


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| | |
|---|---|
| → Losses are very high. | → Losses are very low. |
| → Efficiency is low. | → Efficiency is high. |
| → Due to presence of limiting reactance if high currents are occured those limiting reactors are project the both converters. | → Due to absence of limiting reactance if high currents are occured those limiting reactors are not project the both converters. |

## PROBLEMS

26/12/19

1. A 200V 875rpm, 150A seperatly excited dc motor has armature resistance of 0.06Ω it is fed from a 1-ϕ fully controlled reactifier with an Ac source of 220V, 50Hz. Assuming continous condition mode, calculate.

(i) Firing angle for rated motor torque at 750 rpm.

(ii) Motor speed for $\alpha = 160^\circ$ at rated torque.

Given data.

$V_a = 200V$

$N = 875$ rpm

$I_a = 150A$

$R_a = 0.06\Omega$

$V_s = 220V$

$F = 50Hz$


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(i) Firing angle $\alpha$ = ? rated motor torque at 750 rpm.

$$V_a = \frac{2V_m}{\pi}\cos\alpha$$

$$V_a = \frac{2 \times \sqrt{2}V_s}{\pi}\cos\alpha$$

$V_a$ = ?

$$E_b = V_a - I_a R_a$$

$$E_{b_2} = V_a - (150)(0.06)$$

$$\frac{E_{b_2}}{E_{b_1}} = \frac{N_2}{N_1}$$

$$\frac{E_{b_2}}{E_{b_1}} = \frac{750}{875}$$

$$\frac{E_{b_2}}{191} = \frac{750}{875} = 163.71$$

$$E_{b_2} = 163.71$$

at 875 rpm.

$$E_{b_1} = V_a - I_a R_a$$

$$= (200) - (150)(0.06)$$

$$E_{b_1} = 191$$

$$\frac{E_{b_2}}{E_{b_1}} = \frac{E_{b_2}}{191} = \frac{750}{875} = 163.71$$

$$E_{b_2} = V_a - (150)(0.06)$$

$$163.71 = V_a - (150)(0.06)$$

$$\boxed{V_a = 172.71}$$


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$$V_a = \frac{2V_m}{\pi}\cos\alpha$$

$$172.71 = \frac{2\sqrt{2}\times 220}{\pi}\cos\alpha$$

$$\cos\alpha = \frac{172.71\times\pi}{2\times\sqrt{2}\times 220}$$

$$\cos\alpha = 0.871$$

$$\alpha = \cos^{-1}(0.871)$$

$$\alpha = 29.42^\circ$$

(ii) $N = ?$ at $\alpha = 160^\circ$

$$\frac{Eb_2}{Eb_1} = \frac{N_2}{N_1}$$

$$\frac{Eb_2}{191} = \frac{N_2}{875}$$

$$Eb_2 = V_a - I_a R_a$$

$$Eb_2 = V_a - (150)(0.06)$$

$V_a = ?$

$$V_a = \frac{2V_m}{\pi}\cos\alpha$$

$$= \frac{2\times\sqrt{2}\times V_s}{\pi}\cos\alpha$$

$$= \frac{2\times\sqrt{2}\times 220}{\pi}\cos(160^\circ)$$

$$= \frac{2\times\sqrt{2}\times 220}{\pi}(-0.93)$$

$$V_a = -184.2$$

$$Eb_2 = (-184.2) - (150)(0.06)$$


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$$E_{b_2} = (-184.2) - 9$$

$$E_{b_2} = -193.2$$

$$\frac{E_{b_2}}{E_{b_1}} = \frac{N_2}{N_1}$$

$$\frac{-193.2}{191} = \frac{N_2}{875}$$

$$N_2 = \frac{875 * (-193.2)}{191}$$

$$N_2 = -885 \text{ rpm.}$$

2. A Seperatly excited DC motor of 220V, 1200rpm, 8A, has armature resistance of 0.75Ω. It is fed from a 1-ϕ fully controlled bridge rectifier whose source voltage is 230V, 50Hz assume continous current mode, Determine the following.

(i) Motor Speed at $\alpha = 45°$ and torque of 8 N-m.

(ii) Developed torque at $\alpha = 45°$ and Speed of 800 rpm.

Given data

$V_a = 220\,V$

$N_1 = 1200\,rpm$

$I_a = 8A$

$R_a = 0.75\Omega$

$V_s = 230\,V$

$F = 50\,Hz$


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(i) $N = ?$ at $\alpha = 45^\circ$ at $T = 8$ N-m

$$E_b = V_a - I_a R_a$$

$$K\phi N = V_a - I_a R_a$$

$$K\phi N = \frac{2V_m}{\pi}\cos\alpha - I_a R_a$$

$$K\phi N = \frac{2\times\sqrt{2}\times 230}{\pi}\cos 45^\circ - I_a(0.75)$$

initially at 1200 rpm.

$$E_{b_1} = V_a - I_a R_a$$

$$= 220 - (8)(0.75)$$

$$E_{b_1} = 214\ V$$

$$E_{b_1} = K\phi N_1$$

$$K\phi = \frac{E_{b_1}}{N_1}$$

$$K\phi = \frac{214}{1200} = 0.17$$

$$T = K\phi I_a$$

$$I_a = \frac{T}{K\phi}$$

$$= \frac{8}{0.17}$$

$$= 47.05\ A$$

$$K\phi N = \frac{2V_m}{\pi}\cos\alpha - I_a R_a$$

$$0.17N = \frac{2\times\sqrt{2}\times 230}{\pi}\cos 45^\circ - (47.05)(0.75)$$

$$N = \frac{\frac{2\times\sqrt{2}\times 230}{\pi}\cos 45^\circ - (47.05)(0.75)}{0.17}$$

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$N = 653.75$

(ii) $T = ?$ at $\alpha = 45^\circ$ at 800 rpm

$$T = k\phi I_a$$

$$T = 0.17(I_a)$$

$$E_b = V_a - I_a R_a$$

$$k\phi N = \frac{2V_m}{\pi}\cos\alpha - I_a R_a$$

$$0.17 \times 800 = \frac{2\times\sqrt{2}\times 230}{\pi}\cos(45^\circ) - I_a(0.75)$$

$$I_a = \frac{0.17 \times 800 \times \pi}{2\sqrt{2} \times 230 \cos(45^\circ) - (0.75)}$$

$$I_a = 13.89$$

$$T = 0.17(13.89)$$

$$\boxed{T = 2.36}$$

May 2019 Set(3)

3. A seperately excited DC motor is operating on a 1-$\phi$ semiconverter at a speed of 1200 rpm with input voltage of 320V and back emf is 100 V. The converter is fire symentrically $\alpha = 45^\circ$ & the armature resistance of 5Ω. Calculate avg current & develop torque.

Given data

$N = 1200$ rpm

$V_m = 320$ V

$E_b = 100$ V


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$\alpha = 45^\circ$

$R_a = 5\Omega$

$I_a = ?$

$$E_b = V_a - I_a R_a$$

$$100 = \frac{V_m}{\pi}(1+\cos\alpha) - I_a R_a$$

$$100 = \frac{320}{\pi}(1+\cos 45^\circ) - I_a(5)$$

$$I_a = 14.7\,A$$

$$T = K\phi I_a$$

Consider $K\phi$.

$$E_b = K\phi N$$

$$K\phi = \frac{E_b}{N} = \frac{100}{1200}$$

$$K\phi = 0.08$$

$$T = (0.08)(14.7)$$

$$T = 1.17\ N\text{-}m.$$

4. A 220 V, 1200 rpm 80A seperatly excited DC motor has an armature resistance of 0.2Ω it is fed from a 1-$\phi$ fully controlled rectifier with an ac source of 230 V, 50Hz assume continous conduction. Calculate, (i) firing angle at rated motor torque and -700 rpm.
(ii) Motor should be at $\alpha = 150^\circ$ & half rated torque.


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Given data

$V_a = 220V$

$N_1 = 1200$ rpm

$I_a = 80\,A$

$R_a = 0.2\Omega$

$V_s = 230V$

$F = 50\,Hz$

(i) $\alpha = ?$ at rated motor torque & $-700$ rpm.

$$V_a = \frac{2V_m}{\pi}\cos\alpha$$

$$V_a = \frac{2\times\sqrt{2}\times230}{\pi}\cos\alpha$$

$V_a = ?$

$$Eb_2 = V_a - I_a R_a$$

$$Eb_2 = V_a - (80)(0.2)$$

$Eb_2 = ?$

$$\frac{Eb_2}{Eb_1} = \frac{N_2}{N_1}$$

at 1200 rpm

$$Eb_1 = V_a - I_a R_a$$

$$= 220 - (80)(0.2)$$

$$= 204\,V$$

$$\frac{Eb_2}{Eb_1} = \frac{N_2}{N_1}$$

$$\frac{Eb_2}{204} = \frac{-700}{1200}$$

$$Eb_2 = -119\,V$$


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$$Eb_2 = V_a - I_a R_a$$

$$Eb_2 = V_a - (80)(0.2)$$

$$-119 = V_a - (80)(0.2)$$

$$V_a = -103\ V$$

$$V_a = \frac{2V_m}{\pi}\cos\alpha$$

$$-103 = \frac{2\times\sqrt{2}\times230}{\pi}\cos\alpha$$

$$\boxed{\alpha = 119^\circ}$$

(ii) $\alpha = 150^\circ$

$$\frac{Eb_2}{Eb_1} = \frac{N_2}{N_1}$$

$$\frac{Eb_2}{204} = \frac{N_2}{1200}$$

$$Eb_2 = V_a - I_a R_a$$

$$= \frac{2V_m}{\pi}\cos\alpha\left[-\tfrac{1}{2}I_a\right]R_a$$

$$= \frac{2\times\sqrt{2}\times230}{\pi}\cos 150^\circ - \left(\frac{1}{2}(80)\right)(0.2)$$

$$= -179.2 - 8$$

$$Eb_2 = -187.2$$


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5. The speed of 20 HP, 210V. 1000 rpm dc series motor is controlled by 1-$\phi$ full convertor. The combined field and armature resistance = 0.25Ω, constant $K_{af}$ = 0.03 N-m/$A^2$, $K_{res}$ = 0.075 V-s/rad. The supply voltage is 230V. Assume continous conduction then determine the following for $\alpha = 30^\circ$ and speed 1000 rpm.

(i) Motor current, motor torque.

(ii) Power factor.

Given data

$V_a = 210V$

$N = 1000 rpm$

$R_a + R_f = 0.25\Omega$

$K_{af} = 0.03$ N-m/$A^2$

$K_{res} = 0.075$ V-s/rad

$V_s = 230V$

$\alpha = 30^\circ$

$$\epsilon b = V_a - I_a R_a$$

$$\epsilon b = \frac{2V_m}{\pi}\cos\alpha - I_a(R_a + R_f)$$

$$\epsilon_b = \frac{2\times\sqrt{2}\times 230}{\pi}\cos 30 - I_a(0.25)$$

$$\epsilon_b = 179.42 - I_a(0.25) \quad \text{——} \quad (1)$$

$$\epsilon_b = [K_{af} I_a + K_{res}]\omega$$

$$\epsilon_b = [0.03 I_a + 0.075] \times \frac{2\pi \times 1000}{60}$$


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$E_b = (0.03 I_a + 0.075) \times 104$ ——— (2)

Sub (2) in (1)

$179.42 - I_a(0.25) = (0.03 I_a + 0.075) \times 104$

$179.42 - I_a(0.25) = 3.12 I_a + 7.8$

$179.42 - 7.8 = 3.12 I_a + I_a(0.25)$

$171.62 = 3.37 I_a$

$I_a = 50.92 A$

$T = k_{af} I_a^2$

$T = 0.03 \times (50.92)^2$

$T = 77.78$

$Pf = \frac{V_a I_a}{V_s I_a}$ ; $V_a = \frac{2V_m}{\pi} \cos\alpha$

$V_a = \frac{2 \times \sqrt{2} \times 230}{\pi} \cos 30 = 179.42$

$PF = \frac{179.42 \times 50.92}{230 \times 50.92}$

$PF = 0.78$


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6. A 210 V, 18HP DC Series motor running at 1300 rpm is controlled by 1-$\phi$ full converter. The combined field and armature resistance is 0.75 $\Omega$. And the constants are $K_{af} = 0.03$ N-m/$A^2$, $K_{res} = 0.075$ V-s/rad. Supply voltage is 230 V. Determine current, torque and power factor at $\alpha = 45^\circ$ at 1500 rpm.

Given data

$N = 1300$ rpm

$R_a + R_f = 0.75\ \Omega$

$V_a = 210$ V

$R_a = 0.75\ \Omega$

$K_{af} = 0.03$ N-m/$A^2$

$K_{res} = 0.075$ V-s/rad

$\alpha = 45^\circ$

$N_2 = 1500$ rpm

$E_b = V_a - I_a R_a$

$$E_b = \frac{2V_m}{\pi}\cos\alpha - I_a R_a + R_f$$

$$= \frac{2 \times \sqrt{2} \times 230}{\pi}\cos 45^\circ - I_a(0.75)$$

$$= 146.49 - I_a(0.75) \quad \text{——— (1)}$$

$$E_b = [K_{af} I_a + K_{res}]\omega$$

$$= [0.03 I_a + 0.075] \times \frac{2\pi \times 1500}{60}$$


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$$E_b = [0.03 I_a + 0.075] \times 157 \quad \text{——(2)}$$

Sub (2) in (1)

$$146.49 - I_a(0.75) = (0.03 I_a + 0.075) \times 157$$

$$146.49 - I_a(0.75) = 4.71 I_a + 0.75 I_a$$

$$134.72 = 5.56 I_a$$

$$I_a = 24.67 \text{ A}$$

$$T = K_{af} I_a^2$$

$$= 0.03 \times (24.67)^2$$

$$= 18.25$$

$$Pf = \frac{V_a I_a}{V_s I_a}$$

$$V_a = \frac{2V_m}{\pi} \cos\alpha$$

$$V_a = \frac{2 \times \sqrt{2} \times 230}{\pi} \cos 45^\circ$$

$$V_a = 146.49$$

$$PF = \frac{146.49 \times 24.67}{230 \times 24.67}$$

$$PF = 0.63 .$$


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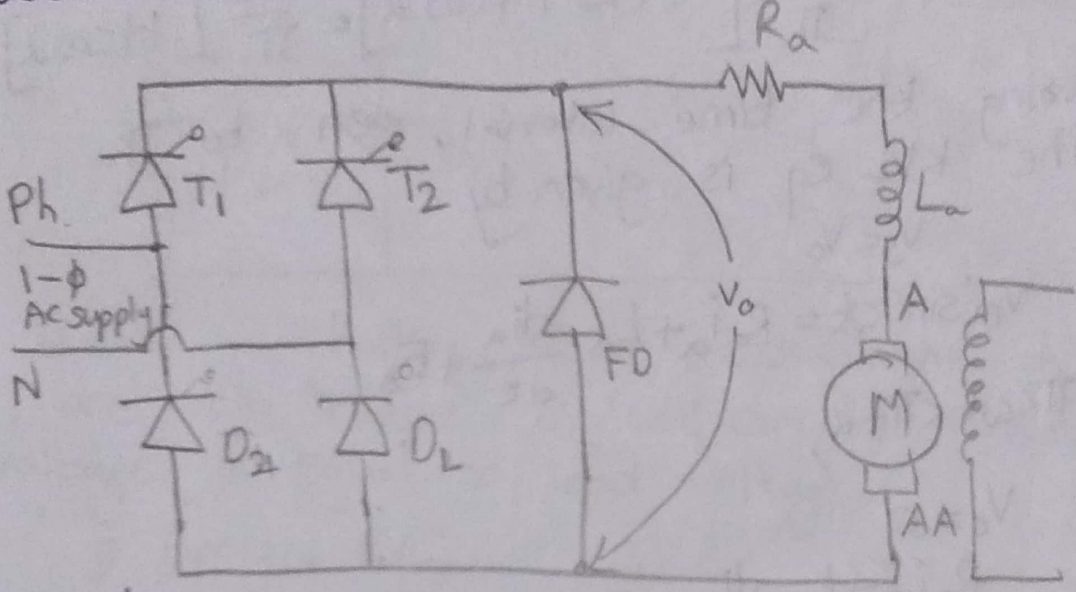
Unit-2

Q)

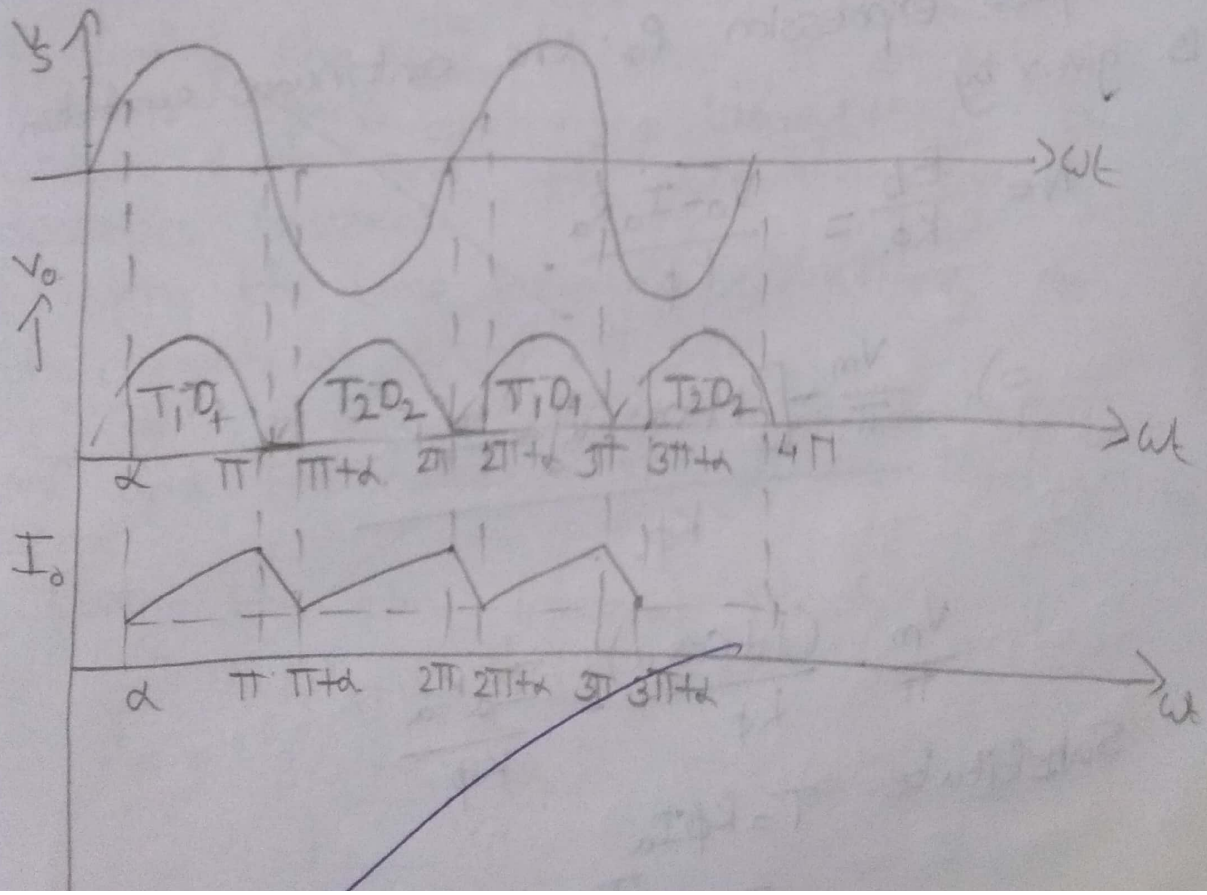
## Operation of DC motors by 1-ϕ converters

In 1-ϕ converters, the quadrant operation is limited to 1,4 (or) 1,2 quadrants i.e, single quadrant operations are mostly used for separately excited DC motor, DC series motors.

### 1-ϕ semi controlled rectifier connected to separately excited DC motor:-




### Output:-





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Avg o/p vtg

$$V_{o\,avg} = \frac{1}{T}\int_0^T f(t)\,dt$$

$$= \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t\, d\omega t$$

$$= \frac{V_m}{\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi}$$

$$V_o = \frac{V_m}{\pi}\left[-\cos\pi + \cos\alpha\right] = \frac{V_m}{\pi}\left[1+\cos\alpha\right]$$

During the time interval, $\alpha$ to $\pi$

The KVL eq is given by

$$V_s = V_o$$

$$V_m \sin\omega t = R_a i_a + L_a \frac{di_a}{dt} + E_b$$

$\pi < \omega t < \pi + \alpha$,

$$V_o = 0$$

$$R_a i_a + L_a \frac{di_a}{dt} + E_b = 0$$

The speed expression for the continuous conduction is given by

$$N = \frac{E_b}{K\phi} = \frac{V_o - I_a R_a}{K\phi}.$$

$$\Rightarrow \frac{\frac{V_m}{\pi}\left[1+\cos\alpha\right] - I_a R_a}{K\phi}$$

$$\frac{V_m}{\pi}\cdot\frac{(1+\cos\alpha)}{K\phi} - \frac{I_a R_a}{K\phi}$$

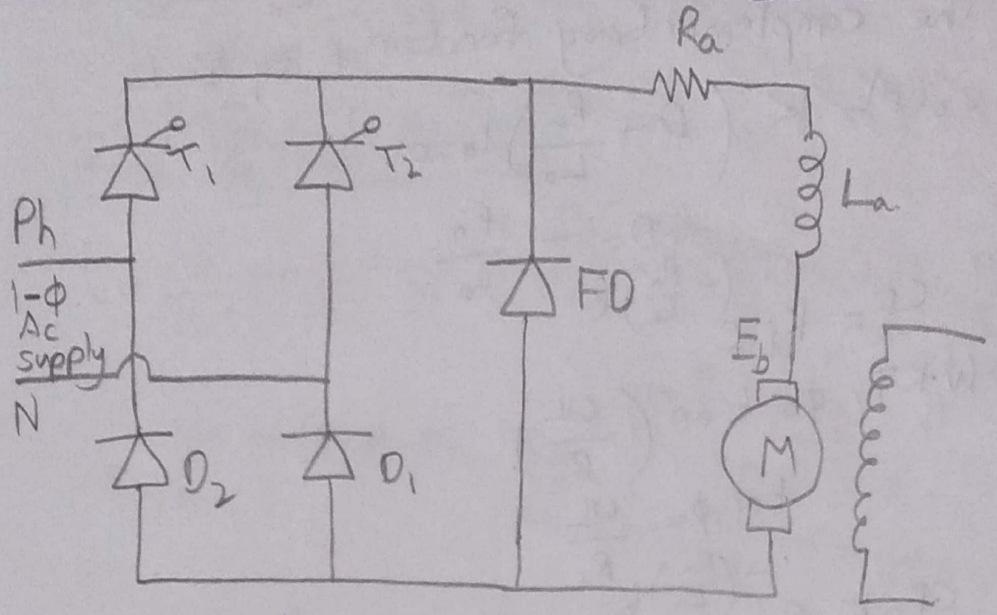
Substitute $T = K\phi I_a$

$$I_a = \frac{T}{K\phi} \text{ then}$$


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$$N = \frac{V_m}{\pi}\frac{(1+\cos\phi)}{K\phi} - \frac{T R_a}{(K\phi)^2}$$

→ In the discontinuous conduction mode




During +ve half cycle i.e, $\alpha < \omega t < \pi$, the thyristor $T_1$ and the diode $D_1$ will conduct and supply voltage is equal to load voltage.

∴ Applying KVL,

$$R_a i_a + L_a \frac{di_a}{dt} + E_b = V_m \sin \omega t \quad \text{—— (1)}$$

During the time interval $\pi < \omega t < \beta$, the inductor starts discharging through the free wheeling diode and the armature current decreases to zero.

During the time interval $\beta < \omega t < \pi + \alpha$ has the current at $\omega t = \beta$ is zero.

∴ The vtg across the load will be the back emf and the current through the load will be zero.

During the time interval $\pi < \omega t < \beta$.

$$0 = R_a i_a + L_a \frac{di_a}{dt} + E_b \quad \text{—— (2)}$$

During $\beta < \omega t < \pi + \alpha$ $\quad I_a = 0 = I_o$ —— (3)

$$V_o = E_b \quad \text{—— (4)}$$


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From (1),

$$\frac{di_a}{dt} + \frac{R_a i_a}{L_a} = \frac{V_m \sin \omega t}{L_a} - \frac{E_b}{L_a} \quad \text{---(5)}$$

The complementary function of eq (5) is

$$\left(D + \frac{R_a}{L_a}\right) i_a = 0$$

$$D = -\frac{R_a}{L_a}$$

$$CF = k_1 e^{\left(-\frac{R_a}{L_a}\right)t}$$

W.K.T, $\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$

$$\tan\phi = \frac{\omega L}{R}$$

$$CF = k_1 e^{-\left(\frac{R_a}{L_a}\right)t}$$

$$= k_1 e^{-\left(\frac{R_a}{L_a \omega}\omega t\right)}$$

$$= k_1 \cdot e^{-\left(\frac{\omega t}{\tan\phi}\right)}$$

$$CF = k_1 e^{(-\omega t \cot\phi)} \quad \text{---(6)}$$

PI of eq (5)

$$\frac{di_a}{dt} + \frac{R_a}{L_a} i_a = \frac{V_m \sin \omega t}{L_a}$$

$$PI_1 = \frac{V_m}{Z} \sin(\omega t - \phi)$$

$$\frac{di_a}{dt} + \frac{R_a}{L_a} = \frac{-E_b}{L_a}$$

$$PI_2 = \frac{-E_b}{R_a}$$

$$I_a = k_1 \cdot e^{-\omega t \cdot \cot\phi} + \frac{V_m}{Z} \sin(\omega t - \phi) - \frac{E_b}{R_a}$$

Applying initial conditions

At $\omega t = 0$, $I_a = 0$


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$$0 = K_1 e^{-\alpha \cot\phi} + \frac{V_m}{Z}\sin(\alpha-\phi) - \frac{E_b}{R_a}$$

$$K_1 = \frac{\frac{E_b}{R_a} - \frac{V_m}{Z}\sin(\alpha-\phi)}{e^{-\alpha\cot\phi}}$$

$$\therefore I_a = \frac{E_b}{R_a} + \frac{V_m}{Z}\sin(\alpha-\phi)$$

$$i_a = \frac{V_m}{Z}\sin(\omega t-\phi) - \frac{E_b}{R_a} - \left[\frac{V_m}{Z}\sin(\alpha-\phi) - \frac{E_b}{R_a}\right] \cdot e^{\alpha\cot\phi} \cdot e^{-\omega t\cdot\cot\phi}$$

$$= \frac{V_m}{Z}\sin(\omega t-\phi) - \frac{E_b}{R_a} - \left[\frac{V_m}{Z}\sin(\alpha-\phi) - \frac{E_b}{R_a}\right] \cdot e^{\cot\phi\,(\alpha-\omega t)}$$

At $\omega t = \pi$ Armature current is given by

$$i_a(\pi) = \frac{V_m}{Z}\sin(\pi-\phi) - \frac{E_b}{R_a} - \left[\frac{V_m}{Z}\sin(\alpha-\phi) - \frac{E_b}{R_a}\right] \cdot e^{(\alpha-\pi)\cot\phi} \quad \text{---(7)}$$

From $\pi \le \omega t \le \beta$. The free wheeling diode operates.

$$0 = i_a R_a + L_a \cdot \frac{di_a}{dt} + E_b$$

$$\frac{di_a}{dt} + \frac{R_a}{L_a} i_a = -\frac{E_b}{L_a}$$

Find the solution.

$$CF = k_2 \cdot e^{-\omega t \cot\phi}$$

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

$$i_a = k_2 \cdot e^{-\omega t \cot\phi} - \frac{E_b}{R_a}$$

Substitute the initial conditions at $\omega t = \pi$

$$i_a(\pi) = k_2 \cdot e^{-\alpha\cot\phi} - \frac{E_b}{R_a}$$

Sub eq(7) in the above equation


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$$K_2 = \frac{V_m}{Z}\left[ e^{\pi \cot\phi} \sin\phi - e^{\alpha \cot\phi} \sin(\alpha-\phi) + \frac{E_b}{R_a} \cdot e^{\alpha \cot\phi} \right]$$

For $\beta < \omega t < \pi + \alpha$

where none of the devices are conducting

∴ The armature current is equal to zero and the o/p voltage $V_a = E_b$.

Then, the avg o/p voltage for discontinuous mode is given by

$$V_a = \frac{1}{\pi}\left[ \int_{\alpha}^{\pi} V_m \sin\omega t \, d(\omega t) + \int_{\beta}^{\pi+\alpha} E_b \, d(\omega t) \right]$$

$$V_a = \frac{1}{\pi}\left[ V_m \cdot [1+\cos\alpha] + E_b \cdot (\pi + \alpha - \beta) \right] \quad -(8)$$

Sub (8) in $V_a = E_b + I_a R_a$

$$\frac{1}{\pi}\left[ V_m(1+\cos\alpha) + E_b(\pi+\alpha-\beta) \right] = E_b + I_a R_a$$

$$E_b = \frac{1}{\pi}\left[ V_m(1+\cos\alpha) + E_b(\pi+\alpha-\beta) \right] - I_a R_a$$

$$E_b\left[ 1 - \frac{1}{\pi}(\pi+\alpha-\beta) \right] = \frac{1}{\pi}\left[ V_m(1+\cos\alpha) \right] - I_a R_a$$

$$E_b\left[ \frac{\pi - \pi - \alpha + \beta}{\pi} \right] = \frac{1}{\pi}\left[ V_m(1+\cos\alpha) \right] - I_a R_a \pi$$

$$E_b = \frac{V_m(1+\cos\alpha) - (I_a R_a)\pi}{\beta - \alpha}$$

Sub $E_b = k \cdot \omega_m$ & $I_a = \frac{T}{K}$

$$k\omega_m = \frac{V_m(1+\cos\alpha) - \left(\frac{T}{K}\right) R_a \cdot \pi}{\beta - \alpha}$$


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*A 1-ϕ 230V 50Hz supply feeds a separately excited DC motor using 2 single phase semiconverters one on the feed side and the other on the armature side. The firing angle of either semiconverters is 0. $R_F$=200Ω & $R_a$=0.3Ω. Load Torque is 50N-m at 900rpm speed and the constant is 0.8. Assume the continuous conduction mode and calculate (i) feed current (ii) firing angle of armature circuit (iii) Power factor.

Sol) Given data

$V$=230V

$f$=50Hz.

$R_F$=200Ω, $R_a$=0.3Ω

$T_L$=50N-m.

$N$=900rpm

$K$=0.8

$I_F$=?, $\alpha_a$=?, $PF$=?

We know that, $V_o = \frac{V_m}{\pi}(1+\cos\alpha)$.

$\alpha$=0.

$$V_o = \frac{\sqrt{2}V_{rms}}{\pi}(1+\cos 0) = \frac{\sqrt{2}\times 230}{\pi}(2) = 207V.$$

$V_f = I_f \cdot R_f \Rightarrow I_f = \frac{V_f}{R_f} = \frac{207}{200} = 1.03$ Amp.

$$\omega = \frac{2\pi N}{60} = \frac{2\pi(900)}{60} = 94.24 \text{ rad/sec}$$

$T \propto \phi I_a$

$T = K\phi I_a$

$$I_a = \frac{T}{K\phi} = \frac{T}{KI_f} \quad [\because \phi \propto I_f]$$

$$= \frac{50}{0.8\times 1.03} = 60.67A$$

$E_b \propto \phi\omega \Rightarrow E_b = K\phi\omega = KI_f\omega$

$E_b = 0.8\times 1.03 \times 94.28$

$E_b = 78V$


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General terminal voltage eq of a DC motor

$V_a = E_b + I_a R_a$

$\Rightarrow \frac{V_m}{\pi}(1+\cos\alpha_a) = E_b + I_a R_a$

$\frac{\sqrt{2}\times 230}{\pi}(1+\cos\alpha_a) = 78 + (60.67)(0.3)$

$1+\cos\alpha_a = 0.93$

$\cos\alpha_a = -0.07$

$\alpha_a = 94.6 \times \frac{\pi}{180}$

$\boxed{\alpha = 1.64}$ rad.

The output power of the converter in armature circuit is given by

$V_a$ & = 96.16V & the armature current $I_a = 60.67$A.

$\therefore$ o/p power $= V_a I_a = 96.16 \times 60.67$

$= 5.8$kW.

The armature current is equivalent to source current but the directions are different

$\therefore I_{o\,rms} = \sqrt{\frac{1}{2\pi}\left[\int_{\alpha}^{\pi} I_a^2\, d(\omega t) + \int_{\pi+\alpha}^{2\pi} I_a^2\, d(\omega t)\right]}$

$= \sqrt{\frac{1}{2\pi}\left[I_a^2(\omega t)_{\alpha}^{\pi} + I_a^2(\omega t)_{\pi+\alpha}^{2\pi}\right]}$

$= \sqrt{\frac{I_a^2}{2\pi}\left[\pi-\alpha+\pi-\alpha\right]} = \sqrt{\frac{I_a^2}{2\pi}\left[2(\pi-\alpha)\right]}$

$= \sqrt{\frac{I_a^2}{\pi}(\pi-\alpha)}$

$= I_a \sqrt{\frac{\pi-\alpha}{\pi}}$


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$= 60.67\sqrt{\frac{180-94.6}{180}} = 41.07$ Amp

$i/p\ pf = \frac{o/p\ power}{i/p\ VA} = \frac{5.8\times10^3}{230\times41.07} = 0.6$ lag

*A 200V 1000rpm 13Amp separately excited DC motor has an armature resistance of 3Ω and an inductance of 100mH. It is fed from a 1-ϕ half controlled rectifier with an AC voltage source of 230V. Calculate motor torque for firing angle $\alpha = 30°$ and speed is 400rpm

Sol) $R_a = 3\Omega$

$L = 100mH$

The critical speed

$$\omega_{mc} = \frac{V_m \cdot R_a}{K \cdot z}\left[\frac{\sin\phi \cdot e^{-\alpha\cot\phi} - \sin(\alpha-\phi)e^{-\pi\cot\phi}}{1-e^{-\pi\cot\phi}}\right]$$

$$\phi = \tan^{-1}\left[\frac{X_L}{R}\right] = \tan^{-1}\left[\frac{2\pi fL}{R}\right]$$

$$= \tan^{-1}\left[\frac{2\pi(50)(100\times10^{-3})}{3}\right]$$

$$= 84.5°$$

$\cot\phi = 0.09$

$e^{-\pi\cot\phi} = e^{-\pi(0.09)} = 0.743$

$e^{-\alpha\cot\phi} = e^{-30\times0.09\times\frac{\pi}{180}}$

$= 0.95$

$z = \sqrt{R_a^2 + X_L^2}$

$= \sqrt{(3)^2 + (2\pi\times50\times100\times10^{-3})^2}$

$= 31.5\Omega$


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The back emf $E_b$ at rated operation is given by

$$E_b = V_s - I_a R_a$$

$$= 200 - (13 \times 3) = 161 \text{ V}$$

$$\omega_m = \frac{2\pi N}{60} = \frac{2\pi \times 1000}{60} = 104.7 \text{ rad/sec}$$

W.K.T, $E_b \propto \omega_m \Rightarrow E_b = K\omega_m$

$$K = \frac{E_b}{\omega_m} = \frac{161}{104.7} = 1.53$$

$$\omega_{mc} = \frac{V_m \cdot R_a}{K \cdot z}\left[\frac{\sin\phi \cdot e^{-\alpha \cot\phi} - \sin(\alpha-\phi) \cdot e^{-\pi \cot\phi}}{1 - e^{-\pi \cot\phi}}\right]$$

$$= \frac{(\sqrt{2} \times 200)(3)\left[0.99 \times 0.95 + 0.81 \times 0.743\right]}{1.53 \times 31.5\left[0.257\right]}$$

$$= 105.66 \text{ rad/sec}$$

Motor critical speed

$$N_{mc} = \frac{60 \times \omega_{mc}}{2\pi} = \frac{60 \times 105.66}{2\pi} = 1008 \text{ rpm.}$$

∴ Continuous conduction is possible as motor speed is less than critical speed

$$V_a = \frac{V_m}{\pi}(1 + \cos\alpha)$$

$$= \frac{\sqrt{2} \times 230}{\pi}(1 + \cos 30)$$

$$= 193.2 \text{ V}$$

The back emf related to 400 rpm

$$\frac{E_{b1}}{E_{b2}} = \frac{1000}{400} =$$

$$\frac{161}{E_{b2}} = \frac{1000}{400} \Rightarrow E_{b2} = 64.4 \text{ V}$$


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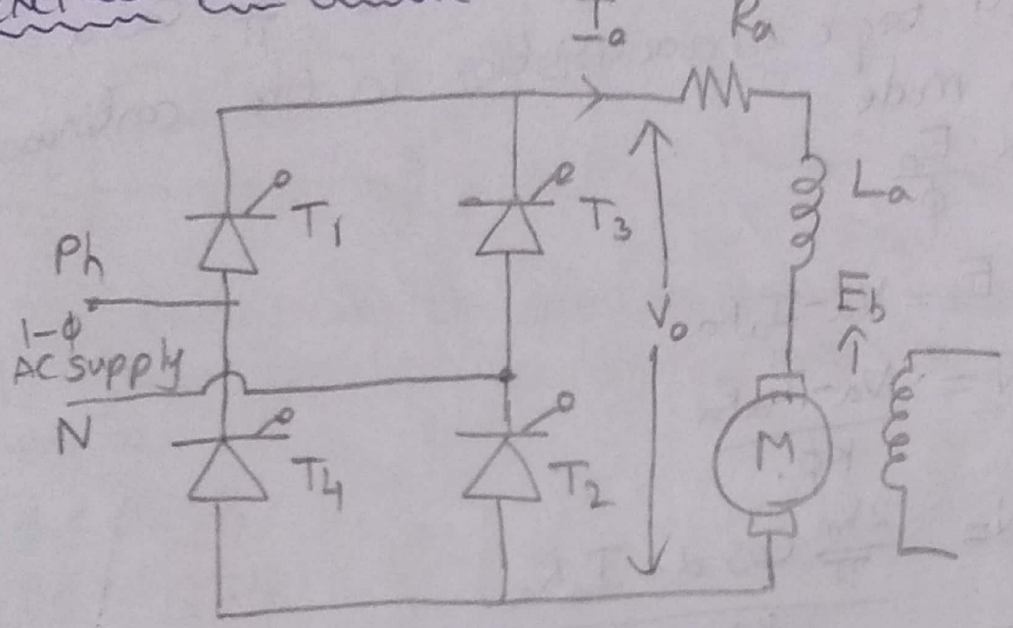
The torque corresponding to the speed 400rpm for firing angle $\alpha = 30^{\circ}$ is given by

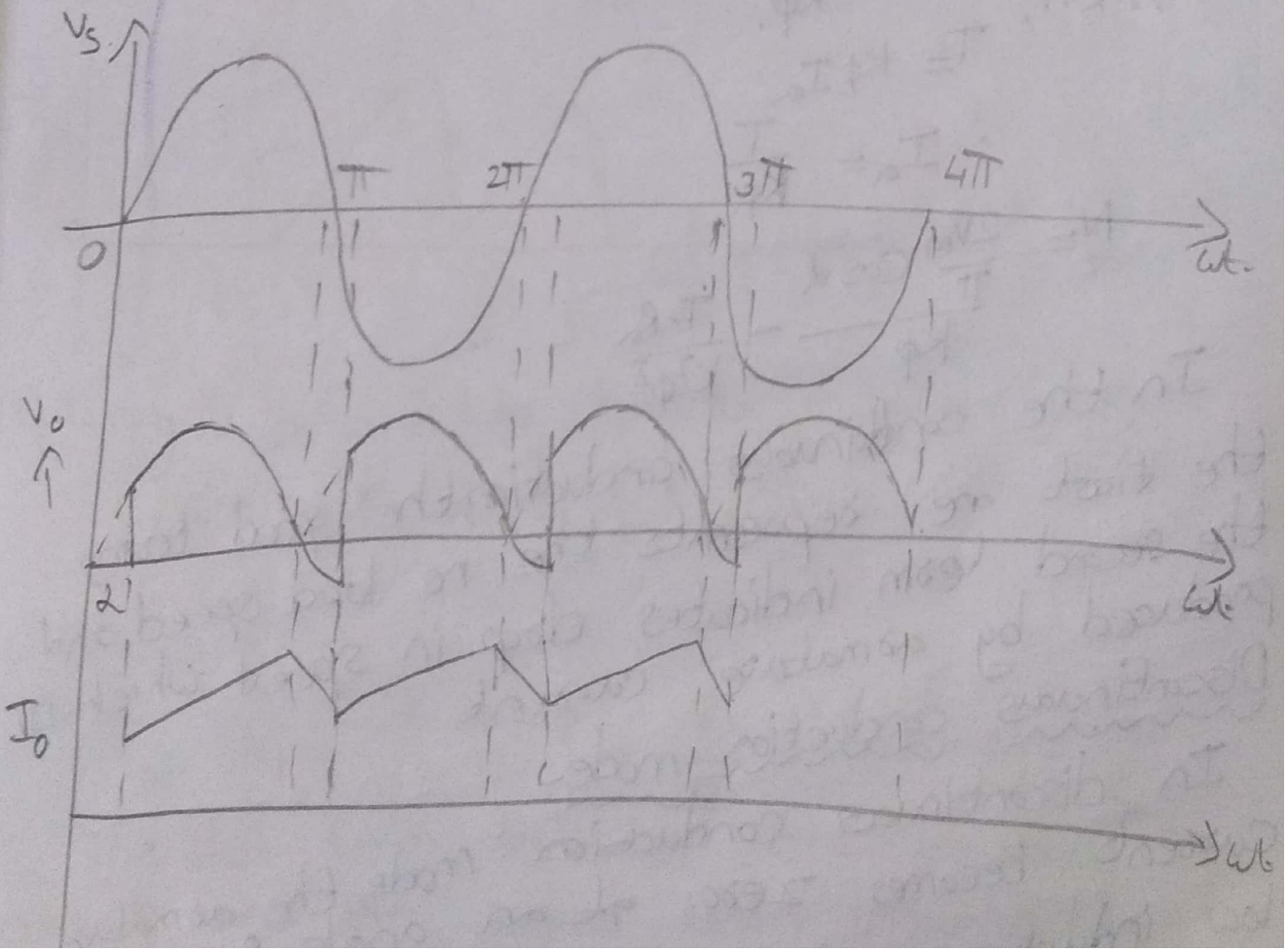
$T \propto I_a$

$T = KI_a$

$= k \cdot \left(\frac{V_a - E_b}{R_a}\right) = 1.53 \left(\frac{230 - 64.4}{3}\right) = 65.6$ (193.2)

1-$\phi$ full converter connected to separately excited DC motor :-





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Avg output voltage is given by

$$V_{avg} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \, d(\omega t)$$

$$= \frac{V_m}{\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi+\alpha} = \frac{V_m}{\pi}\left[-\cos(\pi+\alpha)+\cos\alpha\right].$$

$$= \frac{V_m}{\pi}\left[-\cos\pi\cos\alpha+\cos\alpha\right] = \frac{2V_m}{\pi}\cos\alpha.$$

The speed torque characteristics in the continuous conduction mode

$$N\alpha \frac{E_b}{\phi}$$

where $E_b = V_a - I_a R_a$

$$N = \frac{V_a - I_a R_a}{K\phi}.$$

$$N = \frac{\frac{2V_m}{\pi}\cos\alpha - I_a R_a}{K\phi}.$$

W.K.T, $T = K\phi I_a$

$$\therefore I_a = \frac{T}{K\phi}$$

$$N = \frac{\frac{2V_m}{\pi}\cos\alpha}{K\phi} - \frac{T \cdot R_a}{K^2\phi^2}$$

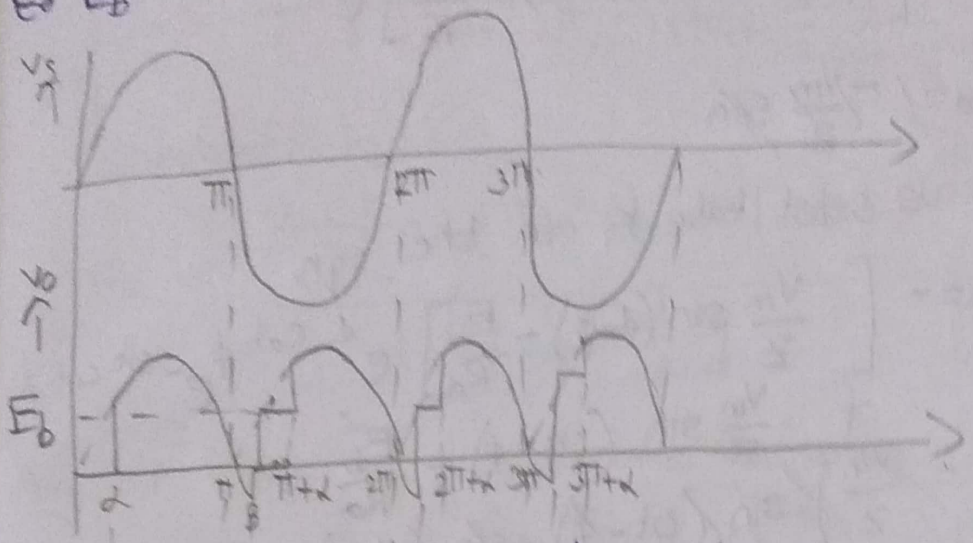
In the continuous conduction, the speed terms the first one represents the no load speed and the second term indicates drop in speed which is produced by armature current

Discontinuous conduction mode:

In discontinuous conduction mode, the armature current becomes zero at an angle $\beta$ due to low inductance of the load.


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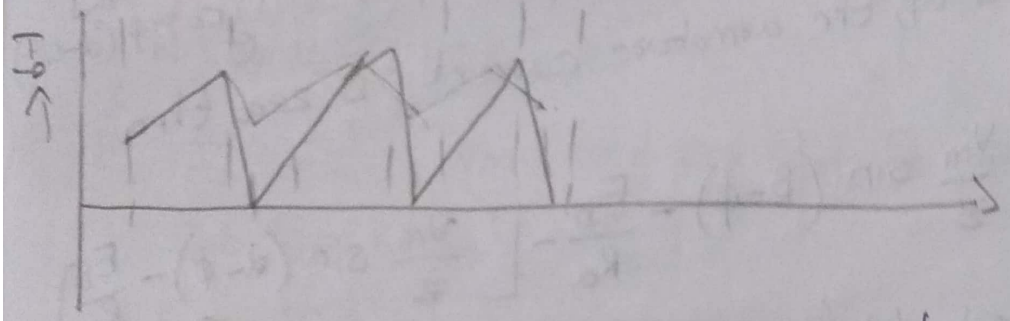
The time interval $\beta < \omega t < \pi + \alpha$ the current is zero and during that time the output voltage is equal to $E_b$.




In this mode the speed regulation is poor and the drive operates in two modes which are given by

(i) $\alpha \leq \omega t \leq \beta$.

(ii) $\beta \leq \omega t \leq \pi + \alpha$




(i) During $\alpha \leq \omega t \leq \beta$, the KVL eq is given by

$$V_m \sin \omega t = E_b + I_a R_a + L_a \frac{dI_a}{dt}$$

The soln is

$$I_a = K_1 e^{-\omega t \cot \phi} + \frac{V_m}{Z} \sin(\omega t - \phi) - \frac{E_b}{R_a}$$

The first term indicates the transient current and the second term indicates the current due to supply and the third term indicates current due to back emf


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At $\omega t=\alpha$, $I_a=0$

$$K_1=-\left[\frac{V_m}{Z}\sin(\alpha-\phi)-\frac{E_b}{R_a}\right]e^{\alpha\cot\phi}$$

$$I_a=I-\frac{V_m}{Z}\sin$$

Let us substitute $K_1$ in the eqn.

$$I_a=-\left[\frac{V_m}{Z}\sin(\alpha-\phi)-\frac{E_b}{R_a}\right].e^{\alpha\cot\phi}e^{-\omega t\cot\phi}$$

$$+\frac{V_m}{Z}\sin(\omega t-\phi)-\frac{E_b}{R_a}$$

$$=\frac{V_m}{Z}\left[\sin(\omega t-\phi)-\sin(\alpha-\phi)\right.$$

$$I_a=\frac{V_m}{Z}\left[\sin(\omega t-\phi)-\sin(\alpha-\phi)\right.$$

$$I_a=\frac{V_m}{Z}\sin(\omega t-\phi)-\frac{E_b}{R_a}-\left[\frac{V_m}{Z}\sin(\alpha-\phi)-\frac{E_b}{R_a}\right].$$

$$e^{\cot\phi(\alpha-\omega t)}$$

At $\omega t=\beta$, the armature current is zero then $I_a=0$.

$$0=\frac{V_m}{Z}\sin(\beta-\phi)-\frac{E_b}{R_a}-\left[\frac{V_m}{Z}\sin(\alpha-\phi)-\frac{E_b}{R_a}\right].$$

$$e^{(\alpha-\beta)\cot\phi}$$

To get the boundary condition b/w continuous conduction and discontinuous conduction, substitute $\beta=\pi+\alpha$.

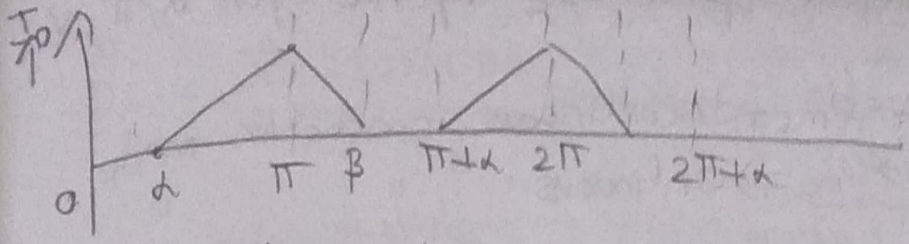
$$0=\frac{V_m}{\pi}\sin(\pi+\alpha-\phi)-\frac{E_b}{R_a}-\left[\frac{V_m}{Z}\sin(\alpha-\phi)-\frac{E_b}{R_a}\right].$$

$$e^{\pi\cot\phi}$$

$$E_b=\frac{V_mR_a}{Z}\left[\sin(\pi+\alpha-\phi)-\sin(\alpha-\phi)e^{-\pi\cot\phi}\right]$$

$$1-e^{-\pi\cot\phi}$$


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Substitute $E_b = K \cdot \omega_{mc}$.

$$\omega_{mc} = \frac{\frac{V_m R_a}{Z}\left[\sin(\pi+\alpha-\phi) - \sin(\alpha-\phi)\, e^{-\pi \cot\phi}\right]}{K\left[1 - e^{-\pi\cot\phi}\right]}$$

Avg o/p voltage in discontinuous conduction mode.

$$V_a = \frac{1}{\pi}\left[\int_{\alpha}^{\beta} V_m \sin\omega t\, d\omega t + \int_{\beta}^{\pi+\alpha} E_b \cdot d(\omega t)\right]$$

$$= \frac{1}{\pi}\left[V_m(-\cos\omega t)_{\alpha}^{\beta} + E_b \cdot (\omega t)_{\beta}^{\pi+\alpha}\right]$$

$$= \frac{1}{\pi}\left[V_m(\cos\alpha - \cos\beta) + E_b(\pi+\alpha-\beta)\right]$$

W.K.T, $V_a = E_b + I_a R_a$

$$E_b + I_a R_a = \frac{1}{\pi}\left[V_m(\cos\alpha - \cos\beta) + E_b(\pi+\alpha-\beta)\right]$$

Sub $E_b = K\phi\omega_m$.

$$K\phi\omega_m + I_a R_a = \frac{1}{\pi}\left[V_m(\cos\alpha - \cos\beta) + K\phi\omega_m(\pi+\alpha-\beta)\right]$$

Substitute $I_a = \frac{T}{K\phi}$.

$$K\phi\omega_m + \frac{T}{K\phi}\cdot R_a = \frac{1}{\pi}\left[V_m(\cos\alpha - \cos\beta) + K\phi\omega_m(\pi+\alpha-\beta)\right]$$

$$\omega_m = \frac{V_m(\cos\alpha - \cos\beta)}{(\beta-\alpha)K\phi} - \frac{T R_a \pi}{K^2\phi^2(\beta-\alpha)}$$

When $\alpha < 90°$, first quadrant operation is possible.

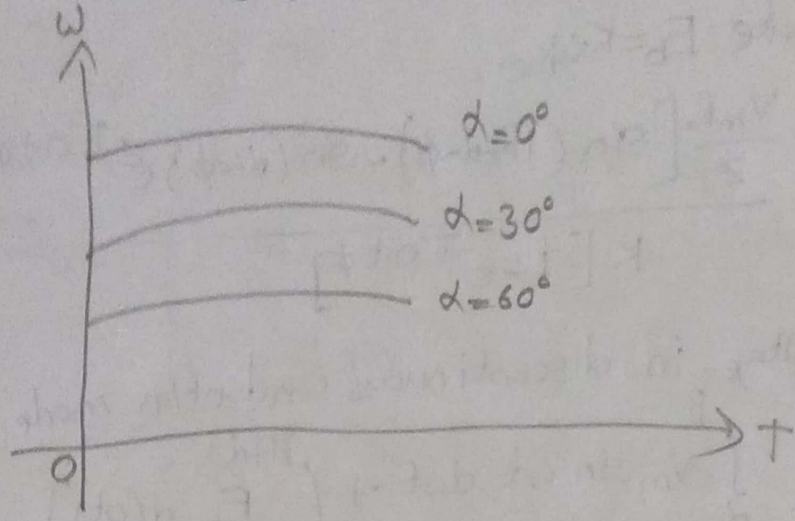
When $\alpha > 90°$, 4th quadrant operation is possible bcoz voltage becomes -ve


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The critical speed $\omega_{mc}$ depends upon $\alpha, \pi, V$ and $R_a$.

When $\omega < \omega_{mc}$ ⇒ discontinuous conduction mode

When $\omega > \omega_{mc}$ ⇒ continuous " "




* A 220V, 1200 rpm 15 Amp separately excited DC motor has an armature resistance of 1.8Ω and inductance of 32mH. The motor is connected to 1-ϕ fully controlled rectifier with an AC voltage of 230V 50Hz. Calculate torque at $\alpha = 60°$ and speed 450 rpm.

Sol) $\omega_{mc} = \frac{V_m \cdot R_a}{K_z} \sin(\alpha - \phi) \left[ \frac{1 + e^{-\pi \cot\phi}}{e^{-\pi \cot\phi} - 1} \right]$

$\phi = \tan^{-1}\left[\frac{X_L}{R_a}\right] = \tan^{-1}\left(\frac{2\pi f L}{R_a}\right)$

$= \tan^{-1}\left(\frac{2\pi \times 50 \times 32 \times 10^{-3}}{1.8}\right)$

$= 79.84°$

$\cot\phi = 0.17$

$e^{-\pi \cot\phi} = 0.58$

$E_b = K\omega_m$

$K = \frac{\omega_m}{E_b} = \frac{(2\pi N/60)}{V - I_a R_a} = \frac{2\pi(1200)/60}{220 - 15(1.8)}$

$= 0.65$


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$K = 1.53$. $Z = \sqrt{R_a^2 + X_L^2} = \sqrt{(1.8)^2 + (0.032)^2} = 10.21$

$$\omega_{mc} = \frac{\sqrt{2} \times 230 \times 1.8}{1.53 \times 10.21} \sin(60 - 79.84)\left[\frac{1+0.569}{0.569-1}\right]$$

~~$= 44.29$ rad/sec~~ $= 46.3$ rad/sec

$$N = \frac{60 \times \omega_{mc}}{2\pi} = \frac{60 \times 44.29}{2\pi} = 4428 \text{ rpm}$$ (Continuous conduction mode)

$$\frac{E_{b1}}{E_{b2}} = \frac{N_1}{N_2} = 72.3 \Rightarrow E_{b1} = V - I_a R_a$$

~~$T = KI_a$~~ $\frac{193}{E_{b2}} = \frac{1200}{450}$

$E_{b2} = 72.3$ V.

$T = kI_a$

$= k\left[\frac{V - E_b}{R_a}\right]$

$= 1.5\left[\frac{220 - 72.3}{1.8}\right] = 108.5$ N-m.

DC series motor :-

In self excited motors, the residual flux is to be considered as the total flux. In series motors, application for drive operation is rarely used bcoz back emf is directly proportional to armature current. as $I_a$ decreases $E_b$ will also decrease which causes discontinuous operation and leads to poor speed regulation

Back emf is given by $E_b = K_a \phi n$

In self excited motors, the residual flux is to be considered bcoz back emf will develop on residual flux which is given by

$E_b = k_a(\phi_a + \phi_{Res})$. N.

The armature flux is proportional to the current flowing through the winding


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$\phi_a \propto I_a$

$\phi_a = k_f \cdot i_a$

$$E_b = k_a k_f \cdot i_a \cdot N + k_a \phi_{res} N.$$

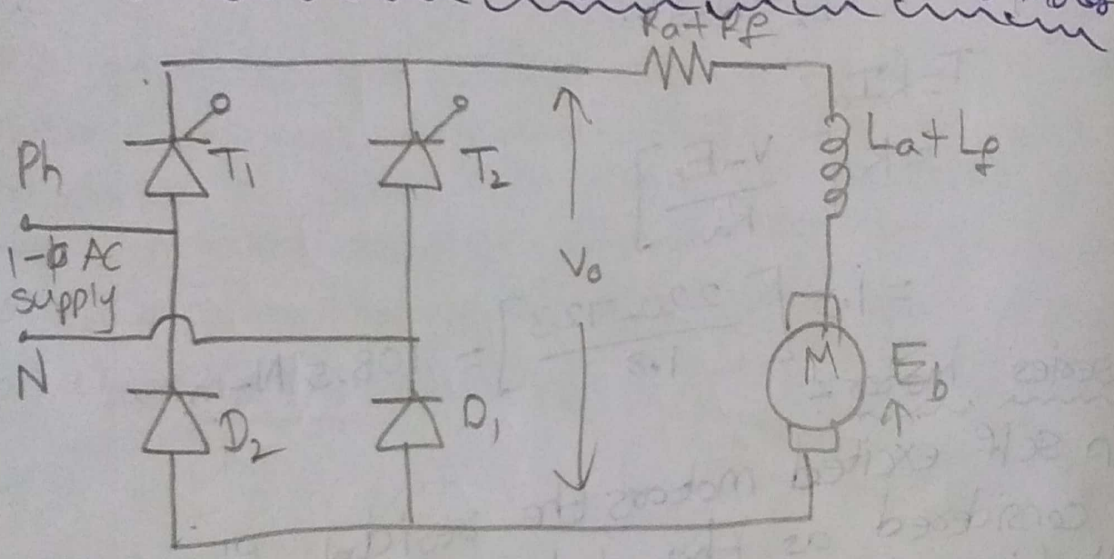
$$E_b = k_{af} \cdot i_a N + k_a$$

The armature voltage is given by

$$V_a = I_a R_a + L_a \frac{di_a}{dt} + E_b.$$

$$v_a = i_a R_a + L_a \frac{di_a}{dt} + k_{af} i_a N + k_{res} N$$

1-$\phi$ semiconverter connected to DC series motor




In 1-$\phi$ semiconverter, the thyristor $T_1$ and the diode $D_1$ will conduct during the +ve half cycle i.e, from $\alpha$ to $\pi$.

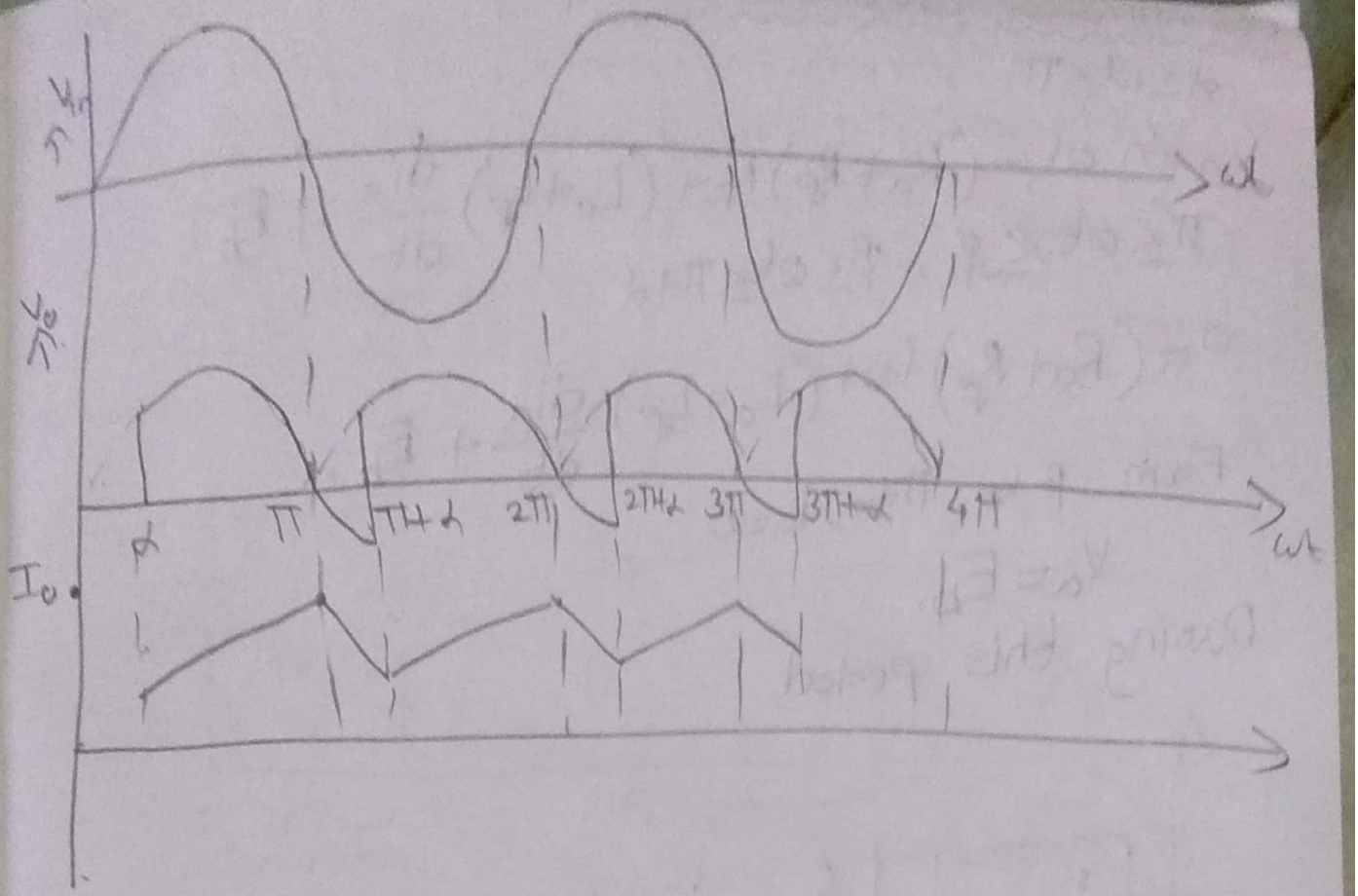
From $\pi+\alpha$ to $2\pi$, thyristor $T_2$ and diode $D_2$ will conduct in the negative half cycle

$\alpha < \omega t < \pi \Rightarrow V_o = V_{in}$

$\pi+\alpha < \omega t < 2\pi \Rightarrow V_o = -V_{in}$

$\pi < \omega t < \pi+\alpha$, Inductor discharges


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For $\alpha < \omega t < \pi$

$$V_m \sin \omega t = (R_a + R_f) i_a + (L_a + L_f) \frac{di}{dt} + E_b$$

where $E_b = k_{af} i_a \cdot N + k_{res} N$

$$V_o \Rightarrow (R_a + R_f) i_a + (L_a + L_f) \frac{di_a}{dt} + k_{af} i_a N + k_{res} N$$

The avg o/p vtg of a semiconverter is given by

$$V_o = \frac{V_m}{\pi} (1 + \cos \alpha)$$

Let us consider

$$\Rightarrow \frac{\frac{V_m}{\pi}(1+\cos\alpha) - (R_a + R_f) i_a - (L_a + L_f) \frac{di_a}{dt}}{k_{af} i_a + k_{res}} = N$$

W.K.T, $T \propto \phi I_a \Rightarrow T \propto I^2$


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## Discontinuous conduction mode:-

$\alpha \le \omega t \le \pi$.

$$V_m \sin \omega t = (R_a + R_f) i_a + (L_a + L_f) \frac{di_a}{dt} + E_b$$

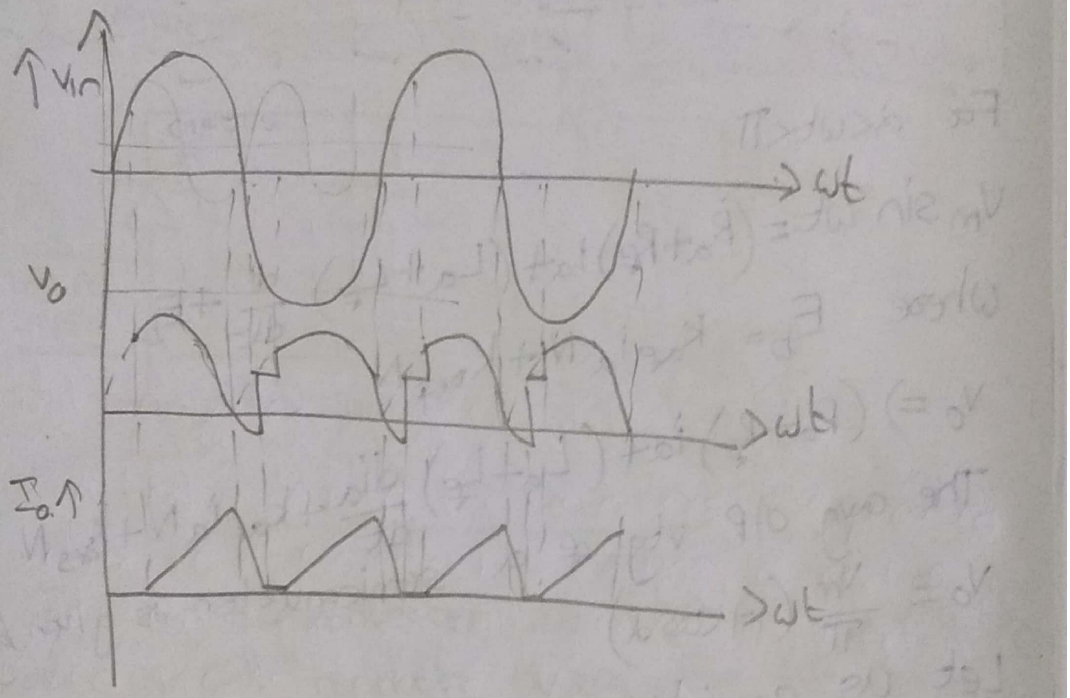
$\pi \le \omega t \le \beta$, $\beta \le \omega t \le \pi + \alpha$

$$0 = (R_a + R_f) i_a + (L_a + L_f) \frac{di_a}{dt} + E_b.$$

From $\beta$ to $\pi + \alpha$, $i_a = 0$

$$V_a = E_b.$$

During this period,




## Dual converter:-

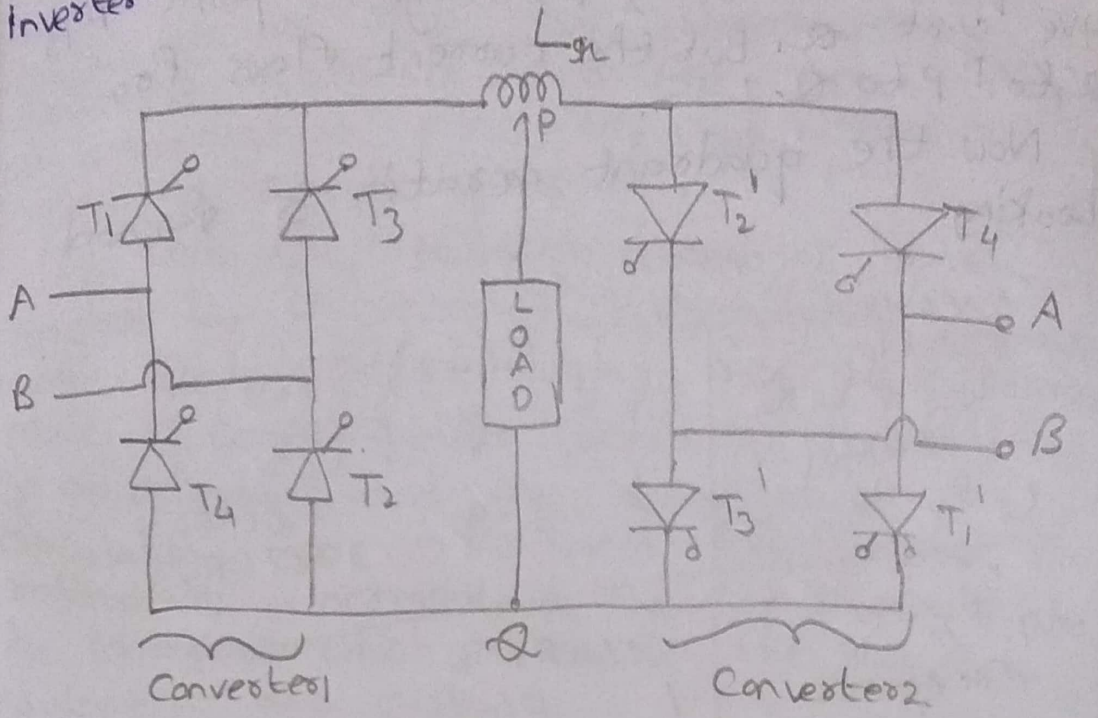
It is a combination of two full converters, which are connected back to back where a four quadrant operation is possible.

In full converter, two quadrant operation is possible and in semiconverter, one quadrant operation is possible.

The dual converter is operated by changing the firing angles of converter 1 and converter 2


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1 will act as a rectifier and the other will act as a inverter.




Dual converter with non-circulating mode

In this mode, only one converter with operate at any time either 1 or 2 if converter 1 has a firing angle of $\alpha_1$ and converter 2 has a $\alpha_2$. The four Quadrant operation is possible by controlling the firing angles

In converter 1, the firing angle $\alpha_1$ is less than 90°, then P is +ve with respect to Q and current flows from P to Q. Therefore, it is forward motoring operation. which is existing in 1st Quadrant.

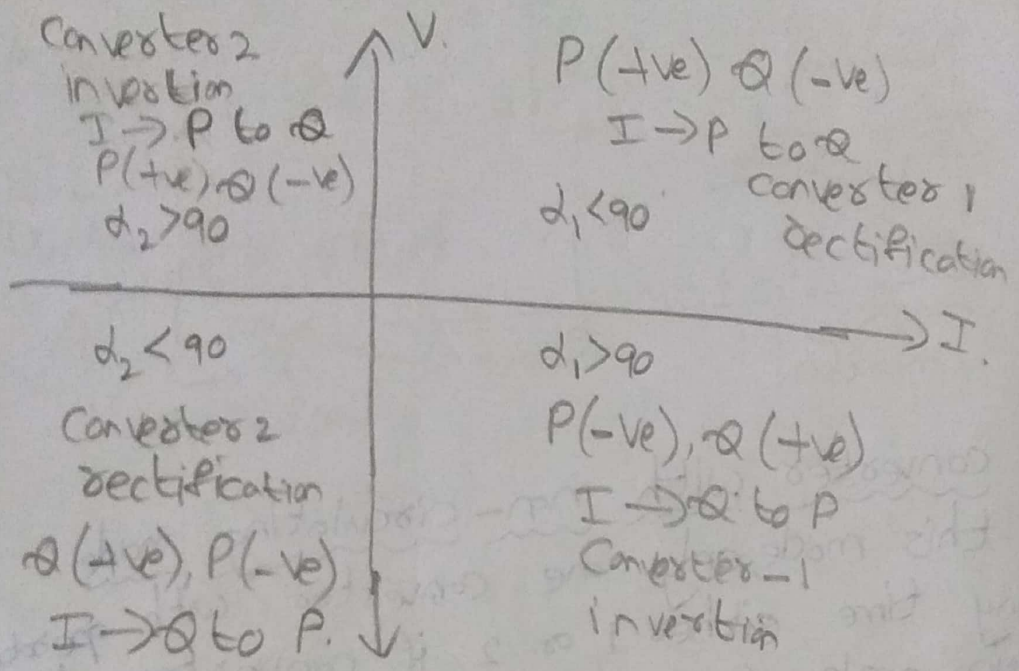
In converter 1, when $\alpha_1 > 90°$, the voltage is reversed i.e, Q is +ve w.r.t P. Now, the current flows from Q to P. It is called reverse braking

Now the converter 1 is switched off and converter 2 is fired. In converter 2, when $\alpha_2 < 90°$, Q is +ve w.r.t P. And the current is flowing from Q to P.


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Now, it gives reverse motoring operation in 3rd quadrant. When $\alpha_2 > 90°$, voltage at point P is +ve w.r.t Q. But the current flows from ~~Q to P~~ P to Q."

Now the quadrant operation is forward braking




## Dual converter with circulating mode:

In this mode, both the converters are operated together i.e if converter 1 is acting in rectification mode then converter 2 will operate in inversion or vice versa. Therefore $V_{o_1} = -V_{o_2}$

$$\frac{2V_m}{\pi}\cos\alpha_1 = \frac{-2V_m}{\pi}\cos\alpha_2$$

$$\cos\alpha_1 = \cos(180 - \alpha_2)$$

$$\cos^{-1}[\cos\alpha] = \cos^{-1}[\cos(180-\alpha_2)]$$

$$\alpha_1 = 180 - \alpha_2$$

$$\alpha_1 + \alpha_2 = 180°$$


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From above condition, the converter 1 or 2 acts in rectification (or) inversion mode. As the voltage magnitudes are same but phases are different across the load the phase difference will occur. which flows the current and is called as circulating current.

To limit the circulating current, a limiting reactor $L_r$ is connected. In circulating current mode bcoz of the limiting reactor, discontinuous mode is converted into continuous mode which is an advantage and the disadvantage of this circulating mode is wherever the motor rating is increased, the reactor size will also be increased which increases the size of the equipment and cost.

The voltage across the reactor in circulating mode

$$V_{o1} - V_{o2} = V_{Lr}.$$

The voltage across the reactor is given by

$$V_{Lr} = 2V_m \sin \omega t$$

If $V_{Lr} = L_r \cdot \frac{dI_{Lr}}{dt}$ $\alpha_1/\omega$

$$I_{Lr} = \frac{1}{L_r} \int_0 V_{Lr}\, dt$$

$$\alpha = \omega t$$

$$\Rightarrow t = \frac{\alpha_1}{\omega}$$

$$I_{Lr} = \frac{1}{L_r} \int_0^{\alpha_1/\omega} 2V_m \sin \omega t\, dt$$

$$= \frac{2V_m}{L_r} \left| \frac{-\cos \omega t}{\omega} \right|_0^{\alpha_1/\omega}$$


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$$= \frac{2V_m}{L_r} \frac{1}{\omega} \left[ -\cos\left(\omega_1 \frac{\alpha_1}{\omega_1}\right) + \cos\alpha \right]$$

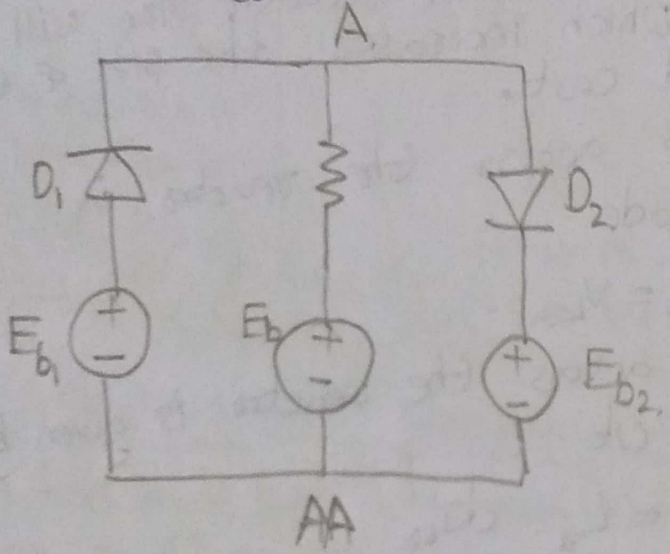
$$= \frac{2V_m}{\omega L_r} \left[ 1 - \cos\alpha_1 \right]$$

Four quadrant operation of DC motor using dual converter in circulating current mode:

In circulating current mode, both the converters are operated in all the quadrants

Quadrant 1:

In I$^{st}$ quadrant, the converter 1 is in rectification mode and converter 2 is in invertion mode.




The current flows from A to AA which is obtained from the converter where the torque is +ve, speed is also +ve.

Quadrant 2:

To obtain II$^{nd}$ quadrant operation, converter 1 is acting as rectifier and converter 2 acts as inverter The output vtg of converter 1 and 2 ie, $E_{b1}$ and $E_{b2}$ are less than back emf $E_b$.

∴ The current direction will change from AA to A The power from the load is fed to converter 2 to the source. This is called regenerative braking.


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Quadrant 3:-

In this mode, converter 1 is in inverting mode and converter 2 is in rectification mode. and the back emf polarity is changed by reversing field terminals. The vtg across the motor is -ve with AA and converter 2 supplies the current in the direction AA to A which is called reverse motoring operation.

Quadrant 4:-

In this mode, converter 1 is in inverting mode and converter 2 is in rectification mode and back emf polarity is changed by reversing field terminals. The vtg across the moto is +ve with AA and converter 1 supplies the current from A to AA.


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