Review :

1) Avg. value of $V_o = \dfrac{2V_m}{\pi}\cos\alpha$ provided

$'i_L'$ is continuous.

2) For $'i_L'$ to be continuous for $90<\alpha<180$, load should be R-L-E.

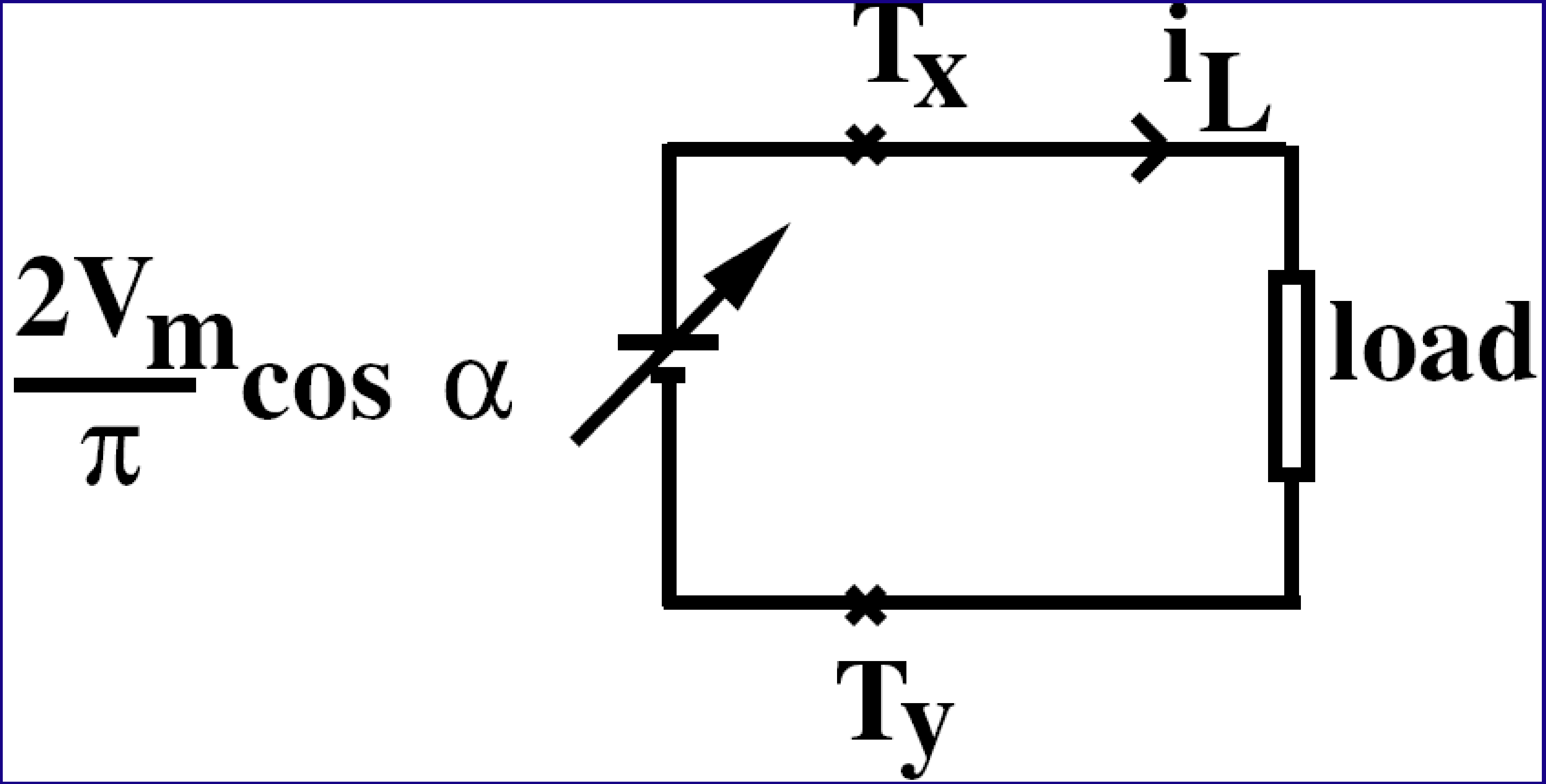
3) For regenerative braking, armature terminals should be reversed for $'i_a'$ reversal.

$\Rightarrow i_a >> I_F$

$\Rightarrow$ Inductive circuit

$\Rightarrow$ momentarily this circuit is broken

$\Rightarrow$ arcing will occur.


$\frac{2V_m}{\pi}\cos\ \alpha$
T_x
i_L
load
T_y

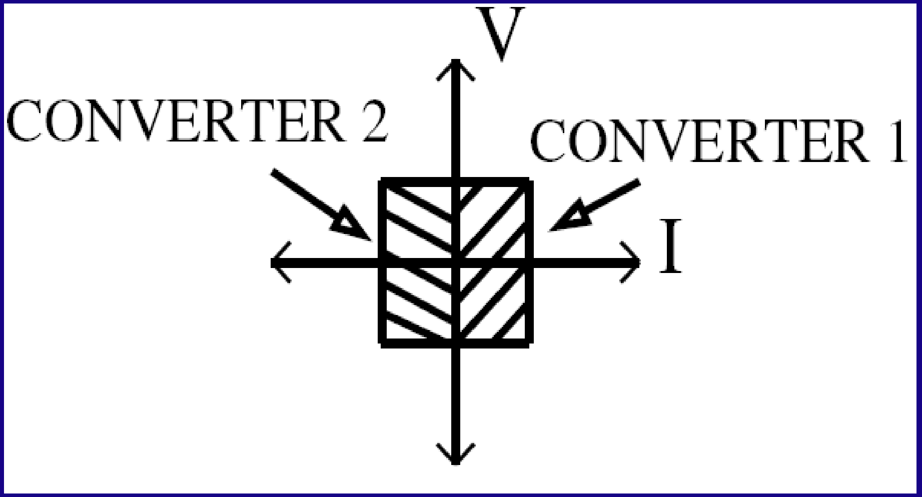
⇒ In a 2-quadrant converter,
'V' can bereversed, but not 'i'.

⇒ use one more bridge.

⇒ Dual converter
connect them back
to back.

⇒ 'i' can be reversed and
flows back to the source
through the 2nd bridge.

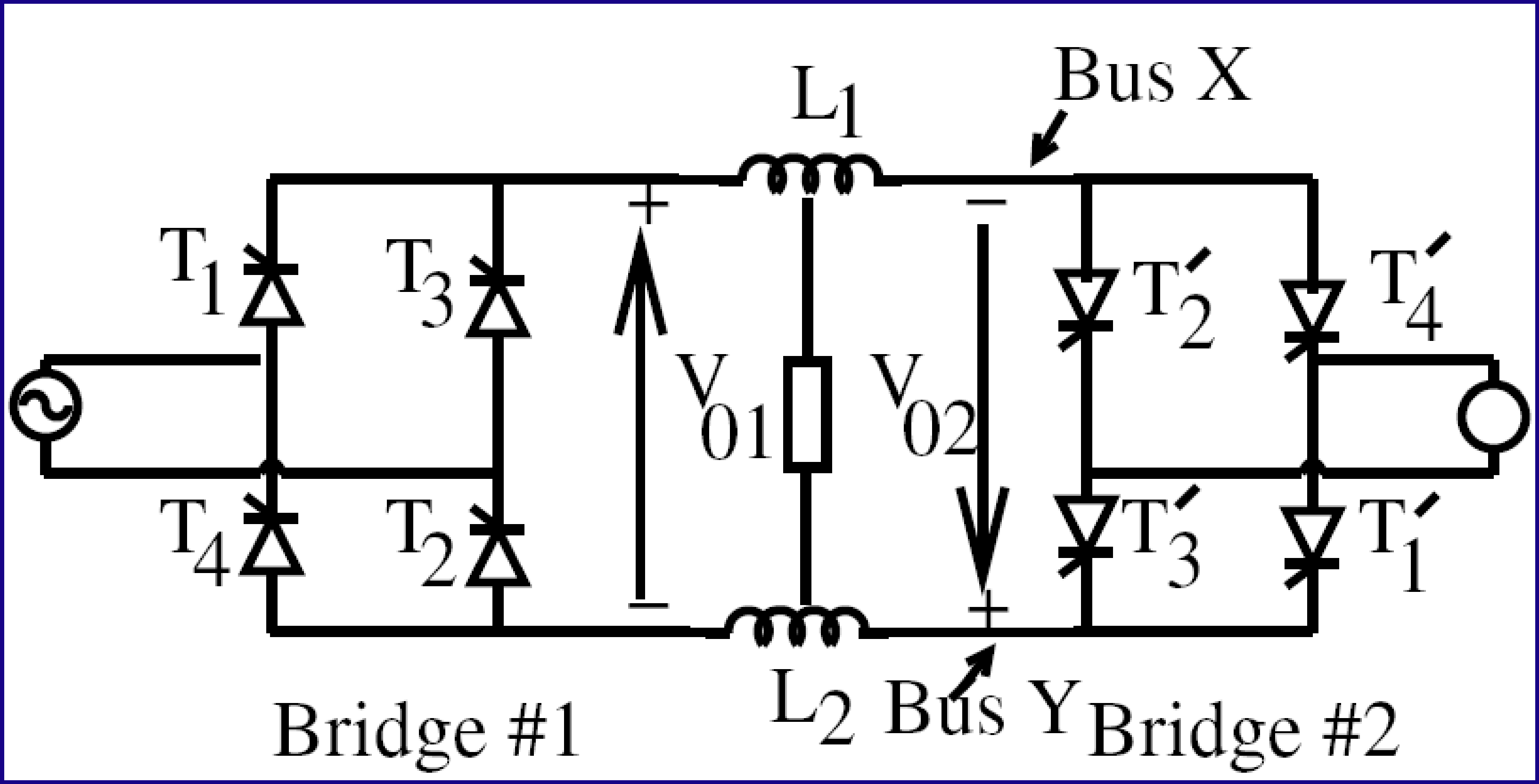
⇒ All 4 quadrant operation.



$\Rightarrow$ o/p 'V' of the converter is pulsating. In order to reduce the current pulsation, generally the inductor is connected in series with the load and the converter. (current cannot change instantaneously)

$T = k\phi I_a$

$\Rightarrow$ Torque pulsation depends on ripple in 'I_a' and not on the o/p 'V' of the bridge.


Bus X
L_1
T_1
T_3
T_4
T_2
+
−
V_{01}
V_{02}
T_2'
T_4'
T_3'
T_1'
L_2
Bus Y
Bridge #1
Bridge #2

Assume that both bridges are ON

Let α_1 be the triggering angle for bridge-1

Let α_2 be the triggering angle for bridge-2

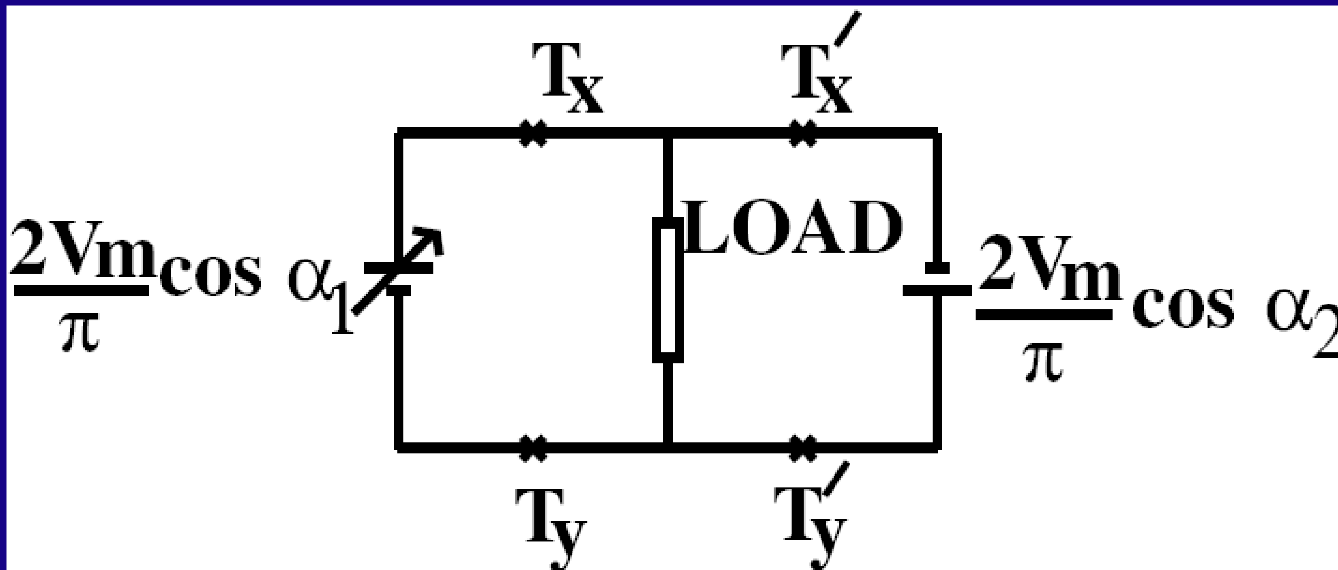
$$\therefore \; V_{01} = \frac{2V_m}{\pi}\cos\alpha_1$$

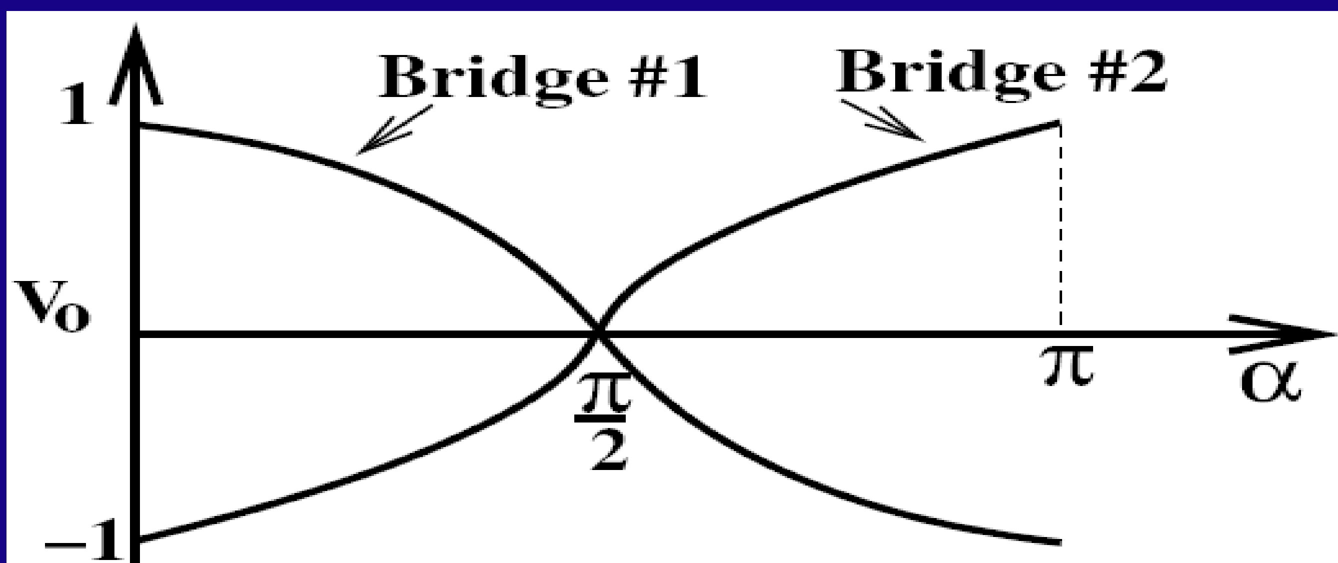
$$V_{02} = \frac{2V_m}{\pi}\cos\alpha_2$$

KVL gives $V_{01} + V_{02} = 0$

$$[\because \; (L\frac{di}{dt})_{avg} = 0]$$

$$\therefore \; \alpha_2 = \pi - \alpha_1$$


T_x
T_x'
LOAD
$\frac{2V_m}{\pi}\cos\alpha_1$
$\frac{2V_m}{\pi}\cos\alpha_2$
T_y
T_y'


Bridge #1
Bridge #2
1
V_o
−1
$\frac{\pi}{2}$
π
α

V_{01} is the voltage w.r.t Bus Y and

V_{02} is the voltage w.r.t Bus X.

Assume that 'L_2' is combined with 'L_1'.

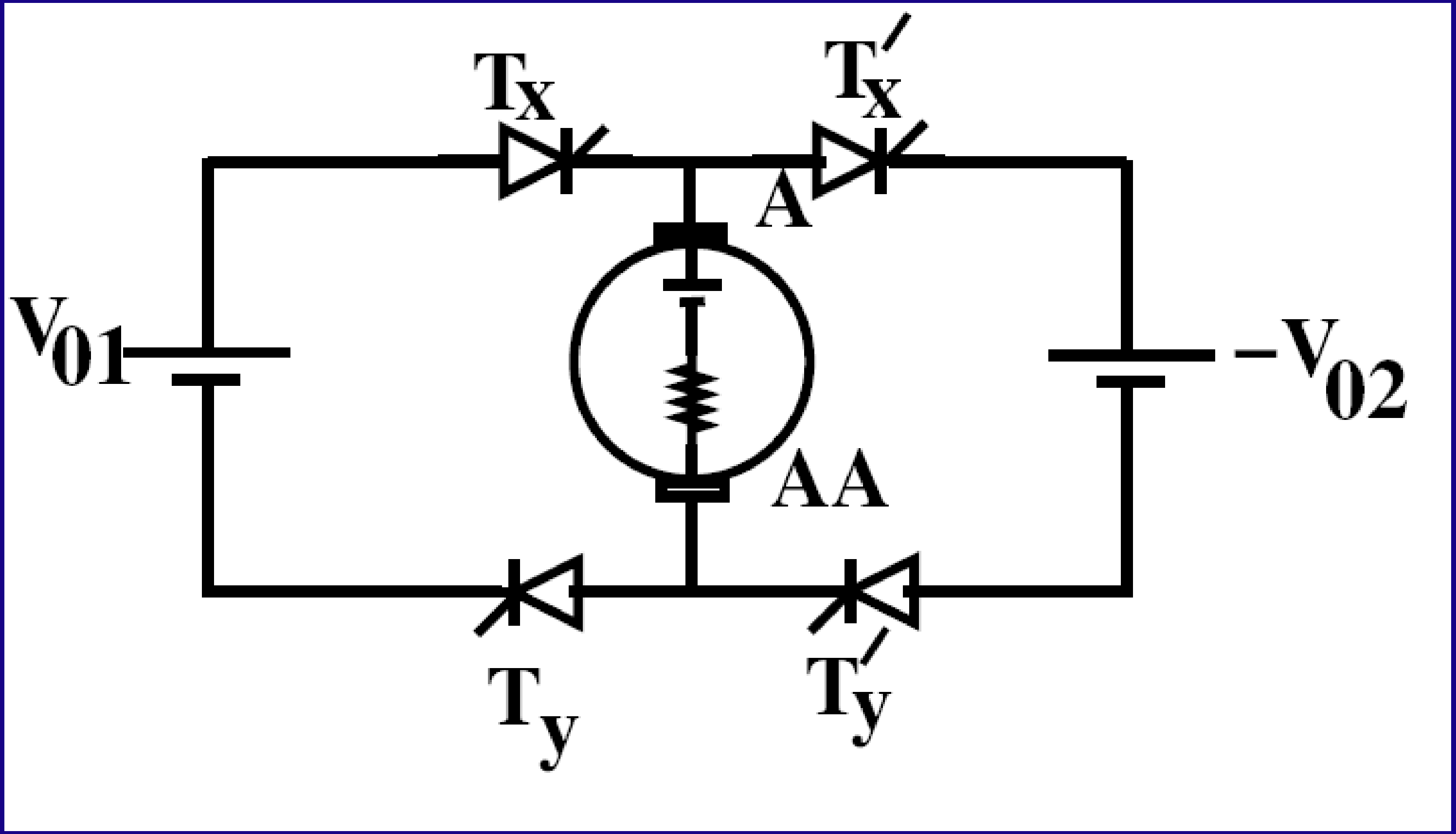
$V_L = V_{01} + V_{02}$

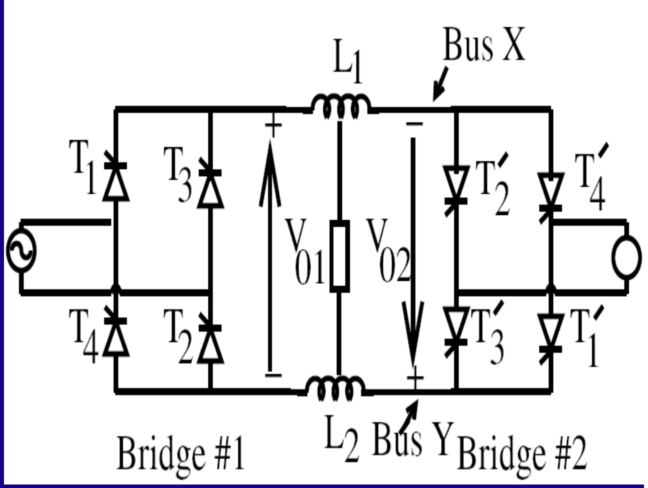
If both are w.r.t Bus Y, then

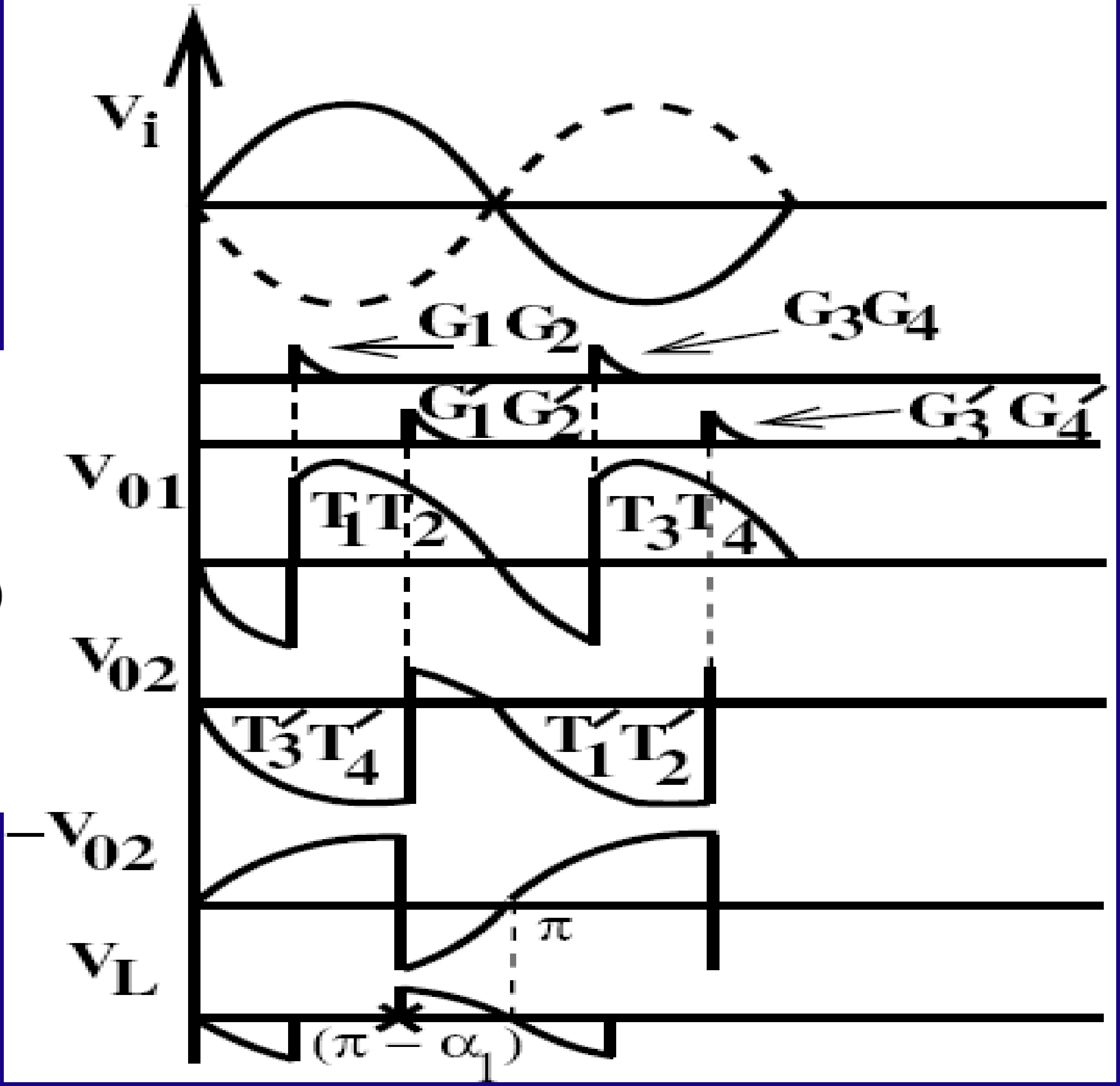
$V_L = V_{01} - V_{02}$

$\Rightarrow$ Average voltage across L = 0, but not instantaneous voltage.

$\Rightarrow$ If both bridges are ON, there will be a circulating current.


T_x
T_x'
A
V_{01}
$-V_{02}$
AA
T_y
T_y'


Bus X
L_1
T_1
T_3
T_2'
T_4'
V_{01}
V_{02}
T_4
T_2
T_3'
T_1'
Bridge #1
L_2 Bus Y Bridge #2


V_i
G_1G_2
G_3G_4
$G_1'G_2'$
$G_3'G_4'$
V_{01}
T_1T_2
T_3T_4
V_{02}
$T_3'T_4'$
$T_1'T_2'$
$-V_{02}$
π
V_L
$(\pi - \alpha_1)$

Assume that the motor is rotating at 'ω' in the clockwise direction and corresponding $E_b = 90\,V$ & $V_{01} = -V_{02} = 95\,V$.

Let $\alpha_1 \approx 45^\circ (\alpha_2 \approx 135^\circ)$

V_{01} is supplying power to the m/c.

I_a is positive which means 'T' is also +ve.

Now, $\uparrow\ \alpha_1$ to 60° or $(\downarrow\ \alpha_2$ to $120^\circ) \Rightarrow V_{01}\ \downarrow$

E_b cannot change instantaneously

$\because$ 'ω' cannot change instantaneously.

$E_b > V_{01}$ generative action

i_a reverses and flows through bridge 2.

$\Rightarrow$ E_b is still +ve, i_a is -ve. $\therefore$ T is -ve.

$\Rightarrow$ Regenerative braking

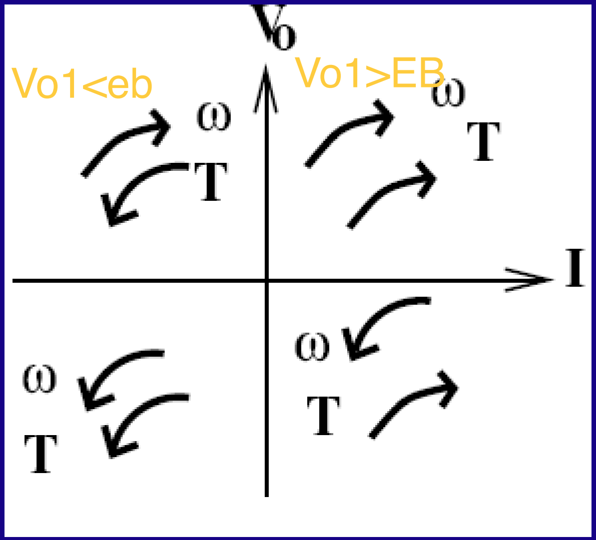
$\Rightarrow$ M/c is still running in clockwise.

$\Rightarrow$ II quadrant operation.

$\Rightarrow \omega \downarrow$.

$\Rightarrow$ continue $\uparrow \alpha_1$ towards 90° Text

($\alpha_2 \downarrow$ towards 90°).



At α_1 = 90°, V_{01} = 0 (ω approaches 0)

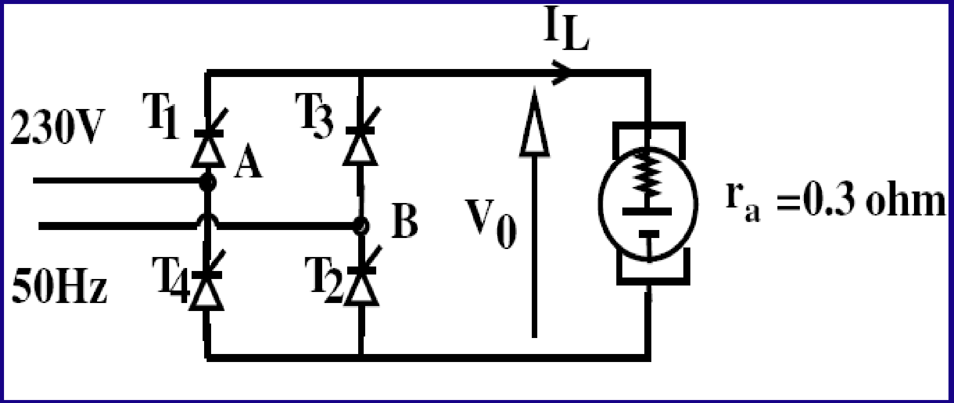
$\uparrow \alpha_1$ beyond 90° ($\alpha_2 \downarrow$ below 90°).

Bridge 1 $\rightarrow$ Inverter and

Bridge 2 $\rightarrow$ Converter.

Bridge 2 supplies power, m/c starts rotating in -ve direction.

'E_b' reverses, $\therefore$ III quadrant (reverse motoring)



Problem 1.1

Armature current $I_a = 30\,A$

EMF constant $= 0.17\ V/rpm$

Assume large L

I is constant in arm. ckt.

In rectifier operation

Determine speed & supply P.F.

Sol : Av $V_0 = \dfrac{2V_m}{\pi}\text{Cos}\,\alpha$

$$= \frac{2 * 230 * \sqrt{2}}{\pi}\text{Cos}\,30$$

$$= 179\ V$$

$\therefore E_b = 179 - 30 * 0.3 = 170\,V$

$$E_b = K\phi\omega$$

$\because$ EMF constant is in V/rpm

$$\therefore E_b = (K\phi)N$$

$$\therefore N = \frac{170}{0.17} = 1000\,\text{rpm}$$

motor current is constant

and ripple free $I_{rms} = 30\,A$

i/p $VA = 230 * 30 = 6900\,VA$

o/p Power $= V_0 I_{av} = 179 * 30\,W$

(Neglecting inverter losses)

$$P.F = \frac{179 * 30}{230 * 30} = 0.77\ \text{lag}$$

Or

RMS value of fundamental component

$$\text{of source current} = \frac{2\sqrt{2}}{\pi} 30 = 27\,\text{A}$$

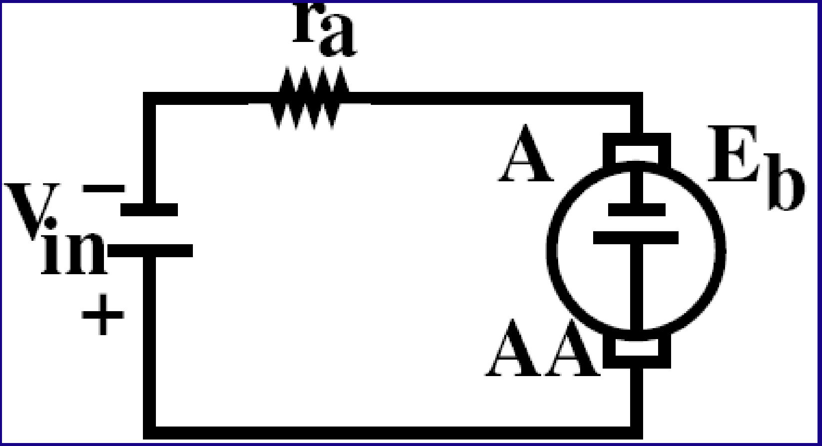
$$\text{Cos}\,\phi_1 = \text{Cos}\,\alpha$$

$$\therefore \text{P.F} = \frac{V_1 I_1 \text{Cos}\phi_1}{V_{rms} I_{rms}} = \frac{27 * \text{Cos}\,30}{30} = 0.779$$

1.2. Regeneration: Polarity of back emf is reversed by reversing the 'ϕ'

Calculate 'α' and power fed back.

Armature current is maintained at previous value.



Sol: At the instant of polarity reversal

$E_b = 170$ V

$\therefore\ V_0 = -170 + I_a r_a$

$= -161\ V = \dfrac{2V_m}{\pi}\cos\alpha$

$\Rightarrow\ \alpha = 141^0$

Power o/p from generator = 170x30

= 5100 W

Armature copper loss = $0.3\text{x}30^2 = 270$ W

$\therefore$ Power fed back = 5100 - 270 = 4800 W

= 161x30 = 4800 W

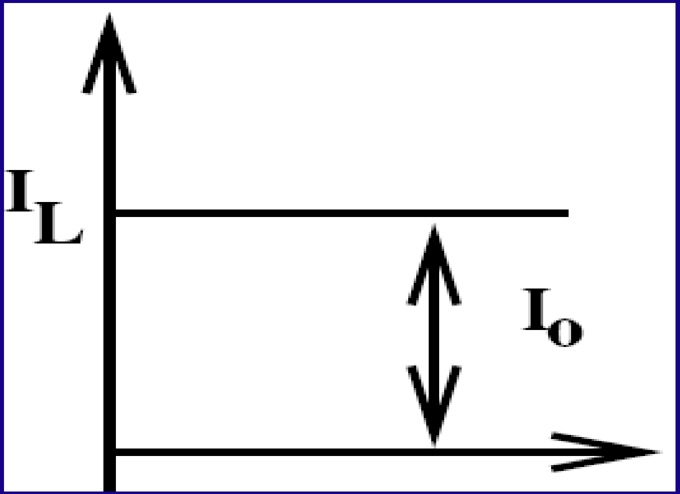
Effect of source inductance

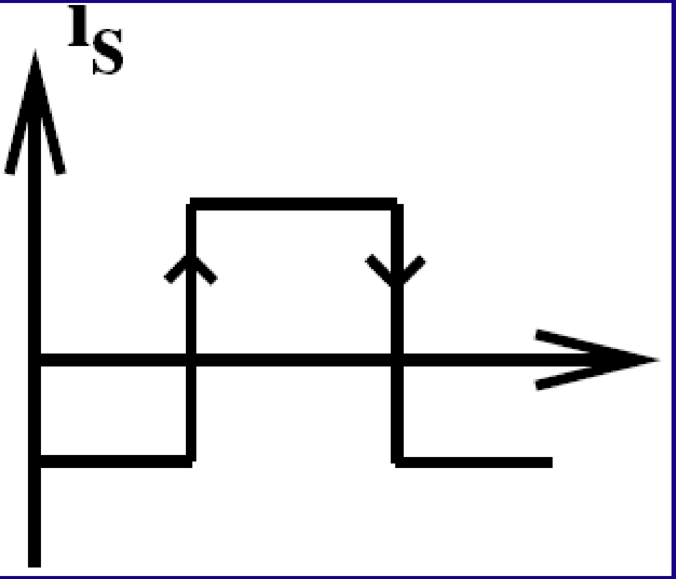
In 1-ϕ bridge, when T_3 is triggered, T_1 turns off instantaneously.

$\Rightarrow$ source L = 0

$\Rightarrow$ there is always some 'L'

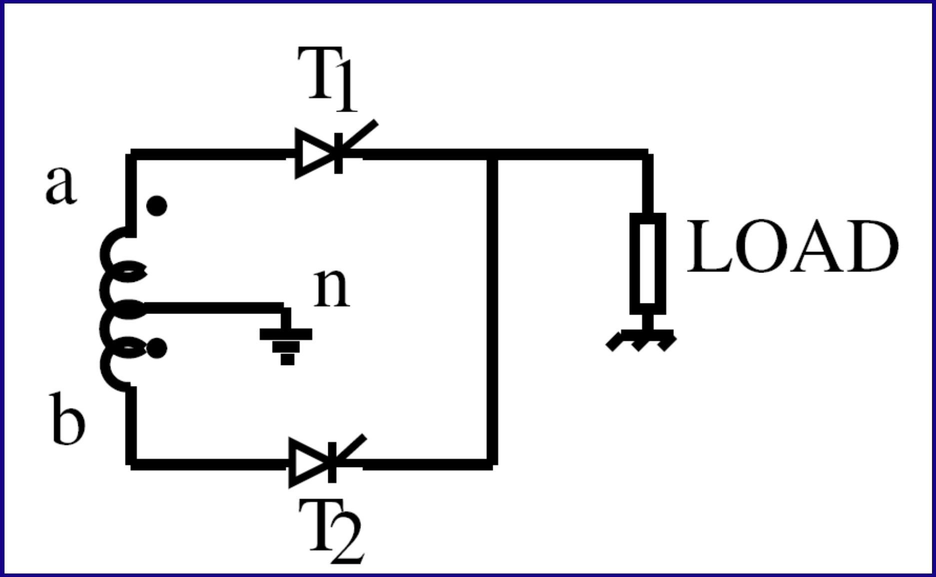
$\Rightarrow$ 'i' cannot change instantaneously.

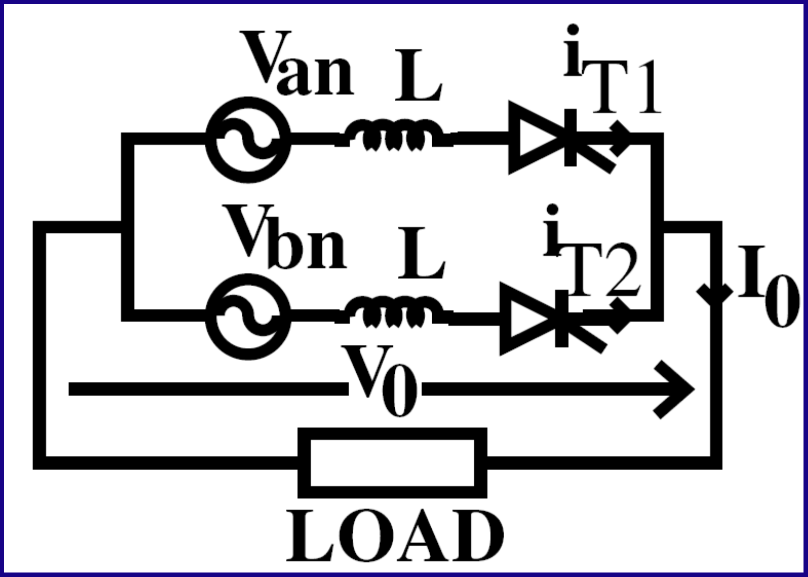




at $\omega t = \alpha$, T_1 is triggered.

at $\omega t = \pi + \alpha$, T_2 is triggered.





$$i_{T1} + i_{T2} = I_o$$

$$\frac{di_{T1}}{dt} = -\frac{di_{T2}}{dt}$$

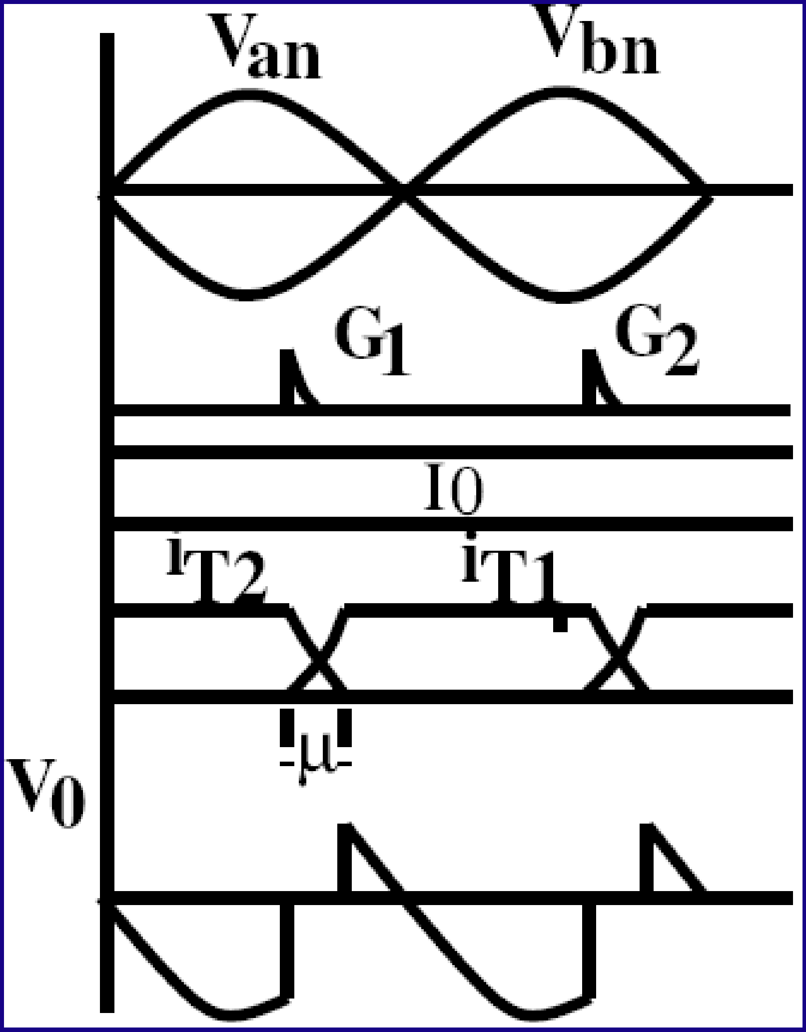
$$V_{an} = -V_{bn} = V_m \sin \omega t$$

Using KVL :

$$V_{an} - V_{bn} = L\frac{di_{T1}}{dt} - L\frac{di_{T2}}{dt}$$

$$\therefore 2V_m \sin \omega t = 2L\frac{di_{T1}}{dt}$$

$$V_0 = V_{an} - L\frac{di_{T1}}{dt} = 0; \quad \text{during } \mu$$



Observation:

Instantaneous V_0 is +ve if L = 0

Instantaneous V_0 is 0 if 'L' is finite.

$\therefore$ Avg. $V_0 \downarrow$

$$V_m \sin \omega t = L\frac{di_{T1}}{dt}$$

$$\frac{V_m \sin \omega t}{\omega} d(\omega t) = L di_{T1}$$

$$\therefore i_{T1} = \int_{\alpha}^{\alpha+\mu} \frac{V_m \sin \omega t \, d(\omega t)}{\omega L}$$

$$\Rightarrow i_{T1} = \frac{V_m}{\omega L}[\cos\alpha - \cos(\alpha+\mu)] = I_0 \text{ at } \mu \text{..................(1)}$$

$\therefore$ Overlap is complete at μ,

$\Rightarrow$ μ is known as the overlap angle

$$\therefore \text{Avg. } V_0 = \frac{2}{2\pi}\int_{\alpha+\mu}^{\pi+\alpha} V_m \sin\omega t \, d(\omega t)$$

$$= \frac{V_m}{\pi}[\cos\alpha + \cos(\alpha+\mu)]$$

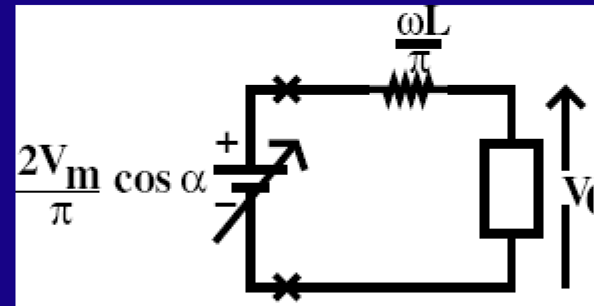
Using Eq.1

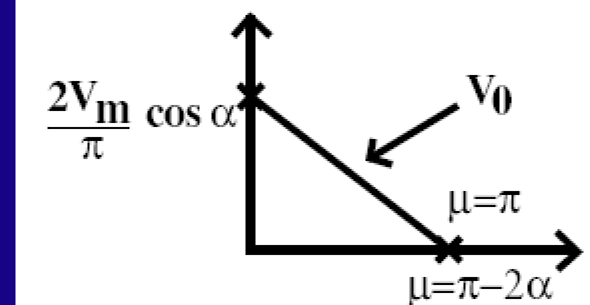
$$\frac{V_m}{\pi}\cos(\alpha+\mu) = \frac{V_m}{\pi}\cos\alpha - \frac{I_0\omega L}{\pi}$$

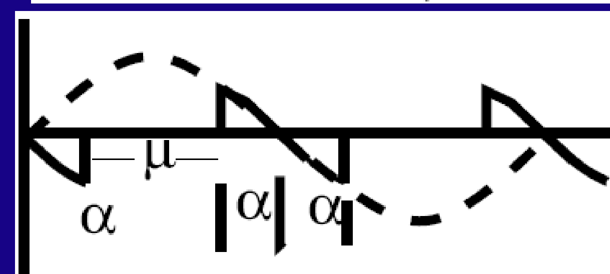
Substituting in the above equation

$$V_0 + \frac{I_0\omega L}{\pi} = \frac{2V_m}{\pi}\cos\alpha$$

$\therefore$Equivalent circuit







$V_0 = 0$ for $\mu=\pi$ or $\pi-2\alpha$

$\mu=\pi$ $\Rightarrow$one overlap mode

$\Rightarrow$no powering mode !

$\Rightarrow$Load is a current source

$\Rightarrow$Magnitude 'I' is independent of terminal 'V'

$\mu=\pi-2\alpha$

$\Rightarrow$Load is pure 'L'

$\Rightarrow$ Possible