EE 8602 Protection & Switchgear III/VI

UNIT - 2.

1. With necessary sketchs discuss in detail about electro magnetic attraction type relay.

The following are some important Electromagnetic attraction relays.

i) plunger type

ii) Hinged armature type

iii) Balanced Beam type

iv) Moving iron polarized type.

i) plunger type.

In this type of relay, the operation is achieved by means of a plunger being moved into the solenoid. An electromagnetic force proportional to the square of air gap flux or the square of the current as produced by the magnetic flux.

This flux is produced by operating quantity. They can be operated on both AC and DC.

The force produced is constant with DC and relay operates when this force goes beyond a prescribed value. When operated on AC electromagnetic force is given by

$$F_e = k I^2$$

$$F_e = k (I_m \sin \omega t)^2$$

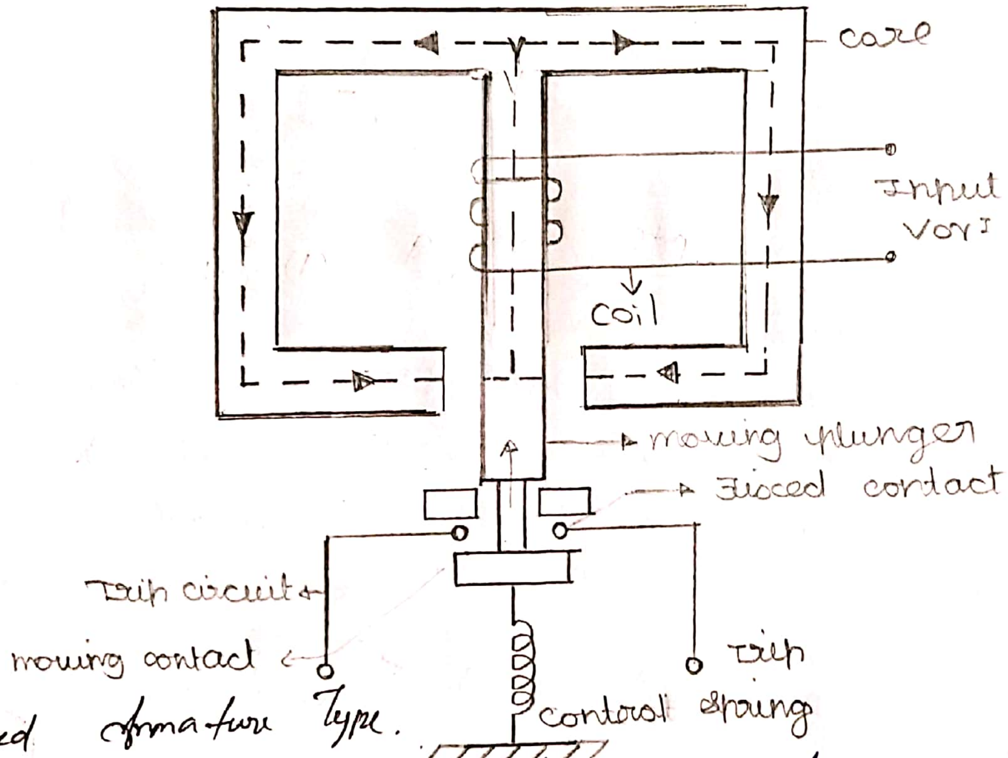
$$F_e = \frac{1}{2} k (I_m^2 - I_m^2 \cos 2\omega t) \rightarrow (1)$$

From eqn (1), electromagnetic force has two components, one constant and independent of time

($\frac{1}{2} K I_m^2$) and the other dependent on time, which pulsates that of frequency of supply.

Restraining force is fixed, the net force is the relay will be destructed early.

In order to avoid this problem, either two windings are placed on the electromagnet or shaded ring is placed on the magnet poles.



ii) Hinged Armature Type.

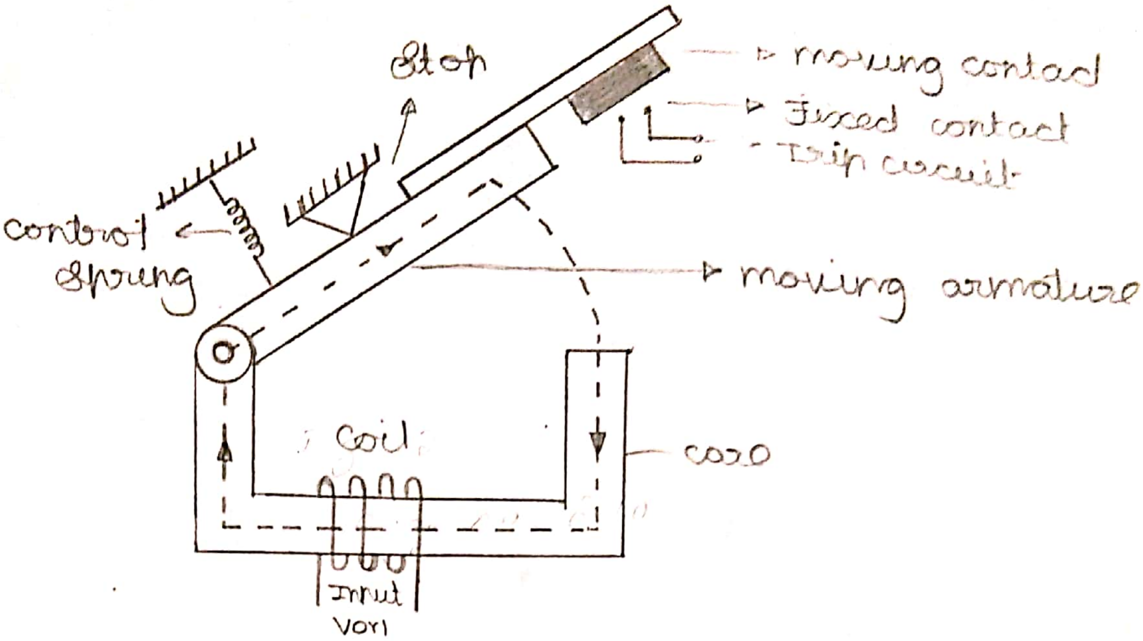
Hinged Armature type relay functions by means of an armature being attracted to electromagnetic poles when coil is energized.

They are mainly used as auxillary relays, example tripping relays.

AC, DC voltage and current relays.

Their VA consumption is low at pick-up value due to only one-contact.

But VA consumption increases as the number of contacts increases.



iii) Balanced Beam Type.

It consists of centrally pivoted horizontal beam, with an armature and coil provided on either sides.

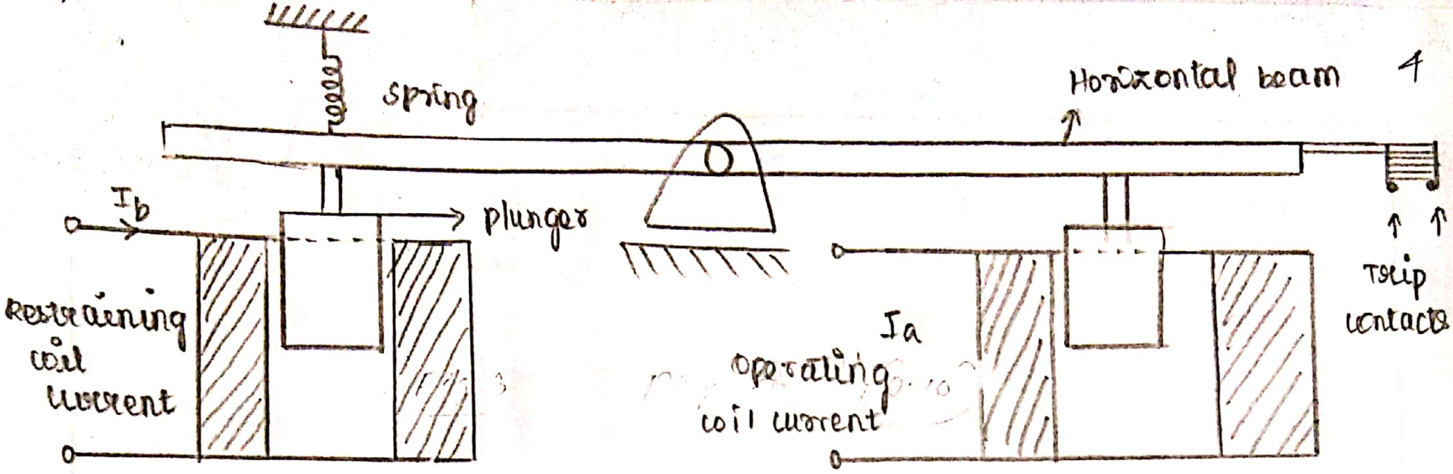
In this relay two quantities A and B are compared. It has low reset to pick-up ratio. The beam resets in horizontal position untill the operating force exceeds the restraining force where current in one coil gives operating force and the other gives restraining force.

A spring or weigh is provided such that under normal conditions the contact remains opened.

During fault condition, the operating torque increases and the beam tilts which in turns closes the contacts.

Then trip coil is energized. The net torque is

$$T = xI_a^2 - yI_b^2$$



T- Net torque

I_a - Operating coil current.

I_b - Restraining coil current

x, y → constant.

The net torque is zero during verge of operation.

$$x I_a^2 = y I_b^2$$

$$\frac{I_a}{I_b} = \sqrt{y/x} = \text{constant}.$$

2. Explain the construction of overcurrent relay with directional scheme.

Directional feature of overcurrent relay.

An over current relay can operate for fault current flow in any direction. i.e either forward or in reverse direction.

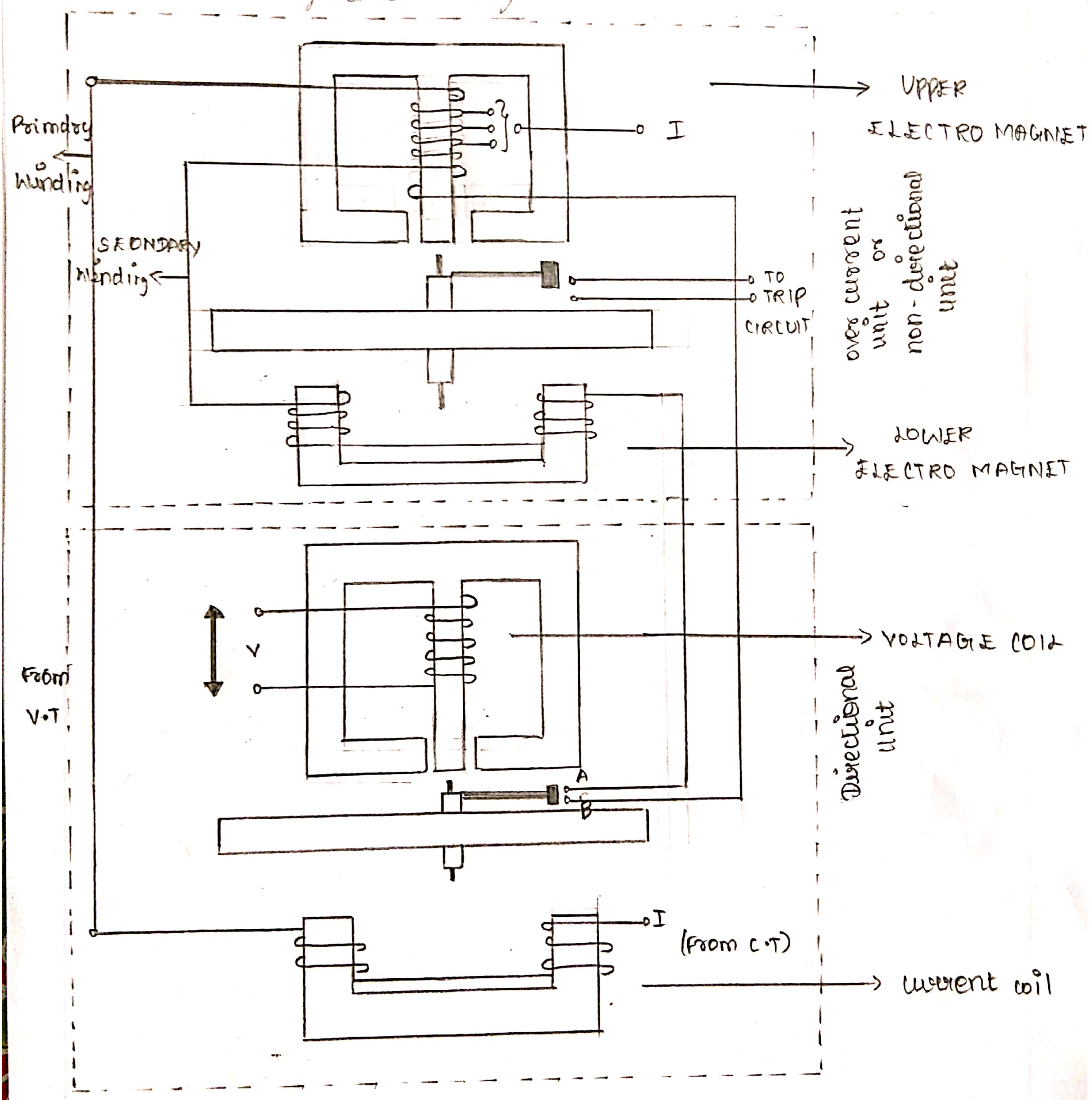
In order to achieve the operation of the relay in forward direction, directional feature is added to the overcurrent relay by adding a directional relay to the overcurrent relay.

Such a relay will respond to fault current in particular direction.

Construction.

It consists of directional unit and non directional unit or over current relay unit.

page 2.15 Fig



The directional unit consists of an induction type directional power relay being fed by voltage and current of the protected circuit through voltage transformers and current transformers respectively.

The directional power relay operates for specified direction of power or current.

The contacts of the current coil of directional unit are connected in series with primary winding in the upper electromagnet of the non-directional or overcurrent unit.

The overcurrent unit consists of induction type overcurrent relay.

Operation.

It operates on the same principle as that of an overcurrent relay. The difference is that in case of of overcurrent relay the operating torque is obtained by the interaction of magnetic fields produced by the current in the primary and secondary circuit.

The operating torque is produced by the interaction of the magnetic field produced by both voltage and current of the protected line.

During normal condition, power or current flows in defined direction hence the directional unit does not operate. and contacts A and B remain open.

The secondary winding of lower electromagnet of overcurrent unit is not energized because this winding completes its circuit path through contacts of directional unit.

During fault conditions, the power or current direction gets reversed.

This causes operation of directional unit and the contacts gets (A & A) closed.

The current flowing through current coil of directional unit also flows through primary winding of upper electromagnet of non direction unit.

Thus flux is produced in primary winding. This flux induces emf in secondary winding of electromagnet of non directional unit.

The circuit path of secondary winding is closed because of closing of contacts (A & B).

The flux developed in secondary winding interacts with primary flux, creating operating torque to rotate the disc.

Hence trip coil is energized.

3. Describe the construction and principle of operation of non-directional induction type overcurrent relay.

It is an overcurrent relay that works on the principle of induction.

This relay is used on AC circuits only and can operate for fault current flow in any direction, that is either in forward or reverse direction.

The relay operates when the current exceeds a predetermined value.

Construction.

It consists of aluminium (metallic disc) which rotates freely in between two electromagnets. The upper electromagnet has two winding namely primary winding and secondary winding.

The primary winding is connected to the secondary of a current transformer present on the protected line

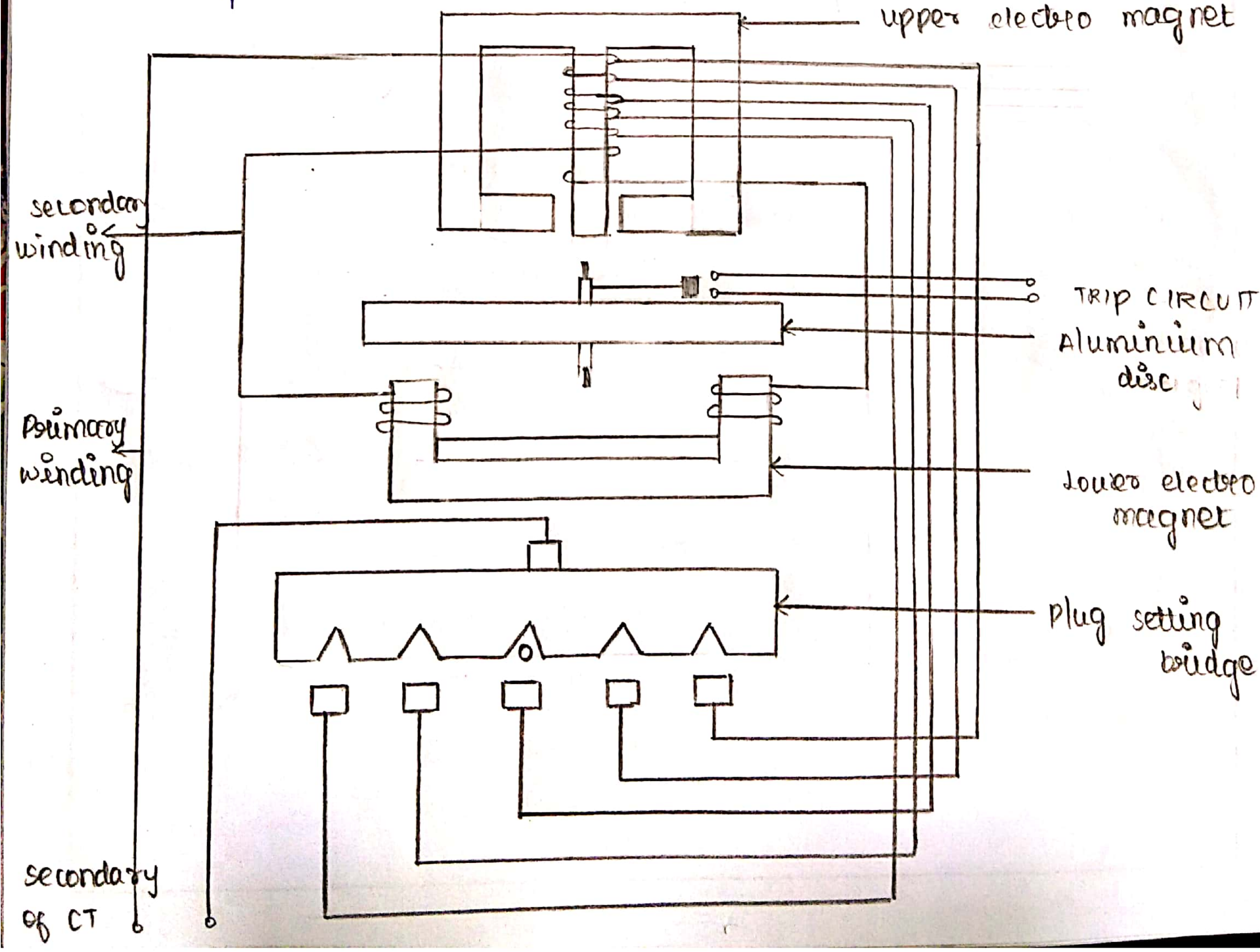
The tappings which are provided on primary winding are connected to plug setting bridge by which the number of turns in operating coil of relay can be adjusted, there by the required current setting can be obtained.

The secondary winding is excited by means of induction from primary and is wound in series with the lower electromagnet windings.

The spiral spring provides restraining torque.

The moving contacts present in the spindle of the disc links two fixed contacts. when the disc rotates.

the angle of rotation of disc can be adjusted to any value (0-360°). Hence the relay time setting can be modified to a desired value.



Operation.

The two fluxes are produced due to a current flowing in the relay coil of the two electromagnets. The interaction of one flux with current causing the other flux produces driving torque.

This driving torque opposes restraining torque developed by the spring.

Under normal operating conditions, restraining torque is greater than the driving torque and the disc remains stationary.

When the current in the line to be protected becomes more than the preset value, the driving torque exceeds the restraining torque resulting in the rotation of disc.

When the disc rotated through a preset angle, the moving contacts join the fixed contacts which make the trip circuit to operate the circuit breaker.

Thus the circuit breaker isolates the faulty section

4. Explain clearly about current balance differential protection

Differential relay.

A relay which functions if the difference between two identical electrical parameters exceeds a preset value is known as differential relay.

The identical electrical parameters can be either current or voltage.

There are two types of differential relay.

1) Circulating current differential relay.

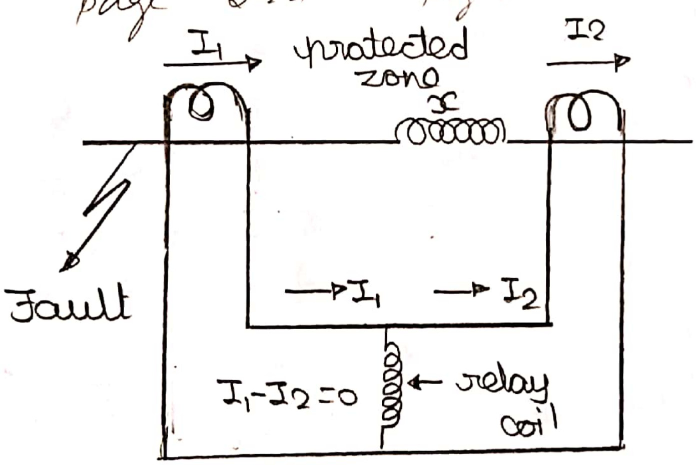
ii) Voltage balance differential relay.

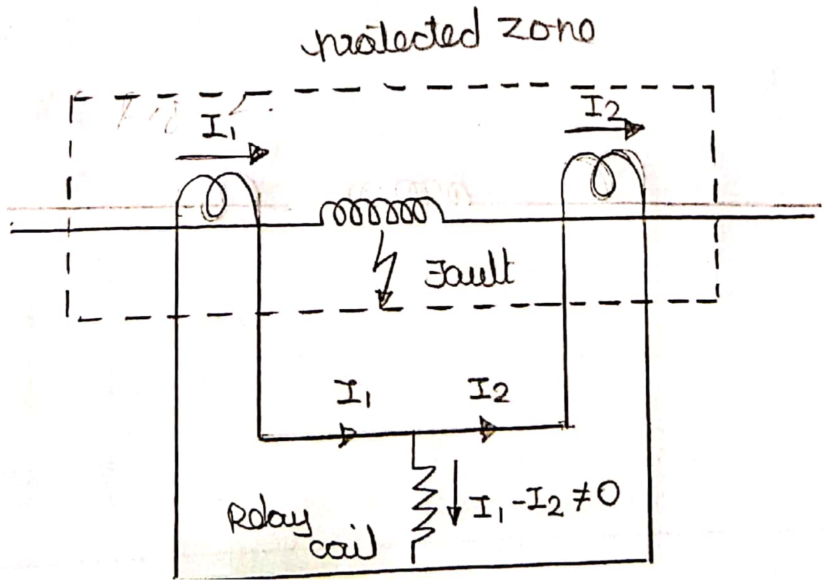
1) Principle of circulating current differential relay.

It is also called Merz-price differential protection. It works on the principle that any fault within an electrical equipment would cause the current entering it to be different from that leaving it. Thus it compares the two currents either in magnitude or in phase or both and provides trip output if the difference exceeds a predetermined set value.

Here two CT's are used at each end of the section to be protected. The relay coil is connected in between the two CT's secondaries at the equipotential point.

page 2.22 Fig 1





From figure (1)

during normal and external fault conditions the protection system is balanced. Thus the current entering the winding (x) or electrical equipment is equal to the current leaving the winding ($I_1 - I_2 = 0$).

From figure (2)

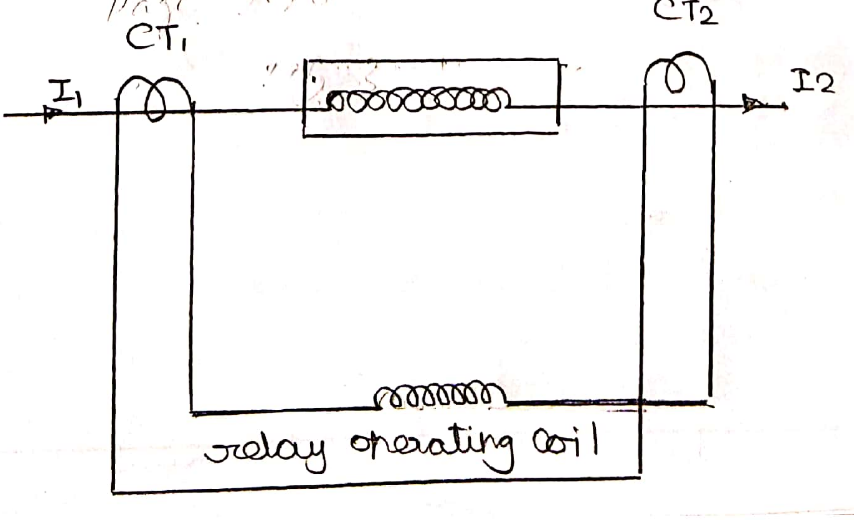
during internal fault (i.e fault in protected zone) the current entering the winding is different from the current leaving it since some current passes through the faulty path ($I_1 - I_2 \neq 0$).

The difference of these currents called the circulating current is fed to the relay operating coil and the relay operates when the operating torque exceeds the restraining torque.

ii) Principle of Voltage Balance Differential protection Relay.

Two CTs are connected at both the ends of the element to be protected as shown below. This relay compares the two voltages, either in magnitude or in phase or both and trips the relay circuit if the difference exceeds a predetermined set value.

Pilot wires are connected by joining two ends of the circuit as shown and joining the secondary winding of CTs to the relay operating coil.



At normal operating conditions same amount of current will flow in both the primary windings of CTs and the voltages in secondary windings of CTs are in opposition and are balanced with each other.

Therefore zero current flows in the relay operating coil. Under faulty conditions, there exists a phasor difference in the currents of primary coil and imbalance in voltages of the secondary winding.

Due to this phasor difference in the ~~current~~ voltage the current flows through the relay operating coil and the relay operates.

5. With neat diagram, describe the construction and principle of operation of negative sequence relay and under frequency relay.

Negative sequence relay.

It is used to protect electrical equipments like generators and motors from unbalanced currents caused due to phase to phase faults.

It consists of a filter circuit that respons to negative sequence components only.

The negative sequence relay or phase imbalance protective device is shown below.

It consists of three current transformers that operate the network.

A single pole relay possessing an inverse time characteristics is placed across the network.

The network is connected in the bridge format by using four impedances Z_1, Z_2, Z_3 and Z_4. Z_1 and Z_2 are non inductive resistances whereas Z_3 and Z_4 are composed of both resistance and inductive reactance.

The Z_2 and Z_3 values are varied such that the currents in these impedances lag by 60° with currents in Z_1 and Z_3 impedances.

The current flowing in phase A are divided into two equal components i.e I_{Z_1} and I_{Z_4} at P.

I_{Z_1} leads I_{Z_4} by an angle 60° as shown.

Fig 1 Pg. no 2.30

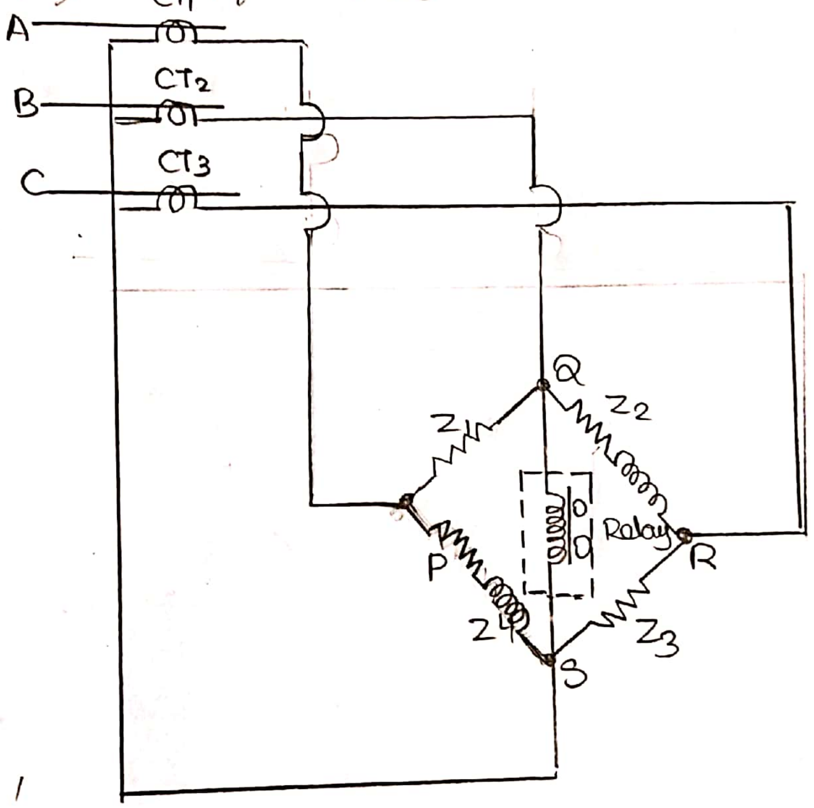
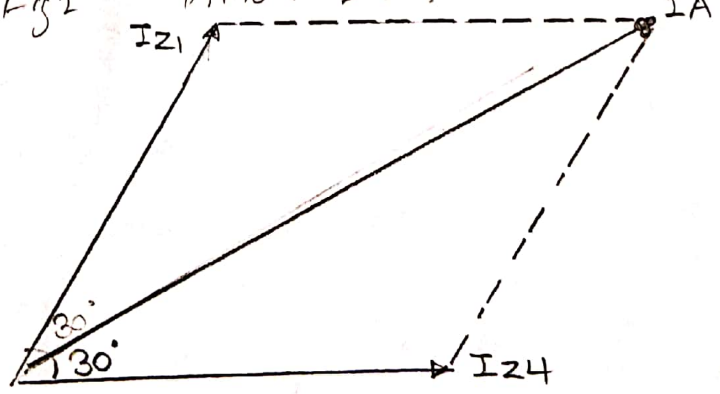


Fig 2 Pg. no. 2.30.



From figure (2): I_{Z_1} leads I_A by 30° and I_{Z_4} leads I_A by 30°

By using parallelogram law of vector addition

$$I_{Z1} = I_{Z4} = \frac{I_A}{\sqrt{3}}$$

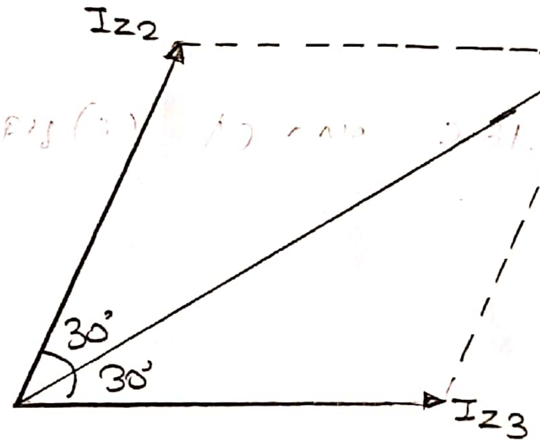
Similarly the current flowing in phase 'C' are divided into two equal components i.e I_{Z2} and I_{Z3} at R_1

I_{Z2} leads I_{Z3} by 60°

$$I_{Z2} = I_{Z3} = I_C/\sqrt{3}$$

I_{Z2} leads I_C by 30°

I_{Z3} leads I_C by 30° as shown below.



Therefore the current flowing through the relay at point q is given by:

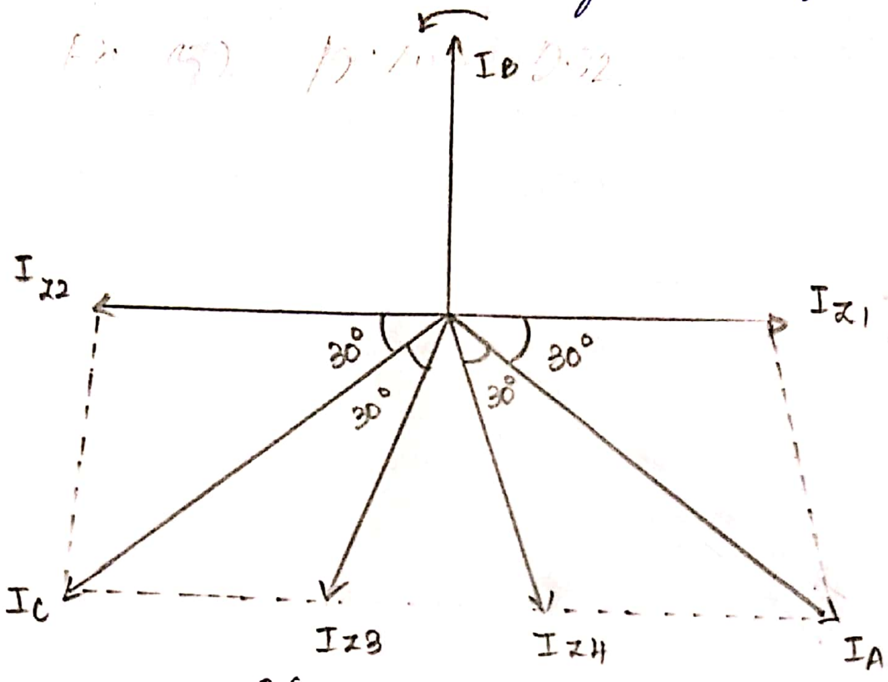
$$I_{relay} = I_{Z1} + I_{Z2} + I_B$$

$$= \left[\frac{I_A}{\sqrt{3}} (\text{leads } I_A \text{ by } 30°) + \frac{I_C}{\sqrt{3}} (\text{leads } I_C \text{ by } 30°) + I_B \right]$$

Negative sequence current.

The current I_{Z1} and I_{Z2} are equal in magnitude but opposite in direction therefore they cancel each other and the current I_B passes through the relay coil and the relay operates.

The relay set value is very low (i.e) below the normal full load rating of the machine because very low unbalance currents can cause a great damage.



Under Frequency Relay.

The relay which operates based on the frequency and produce a tripping signal when the magnitude of frequency drops below a predetermined value is known as under frequency relay.

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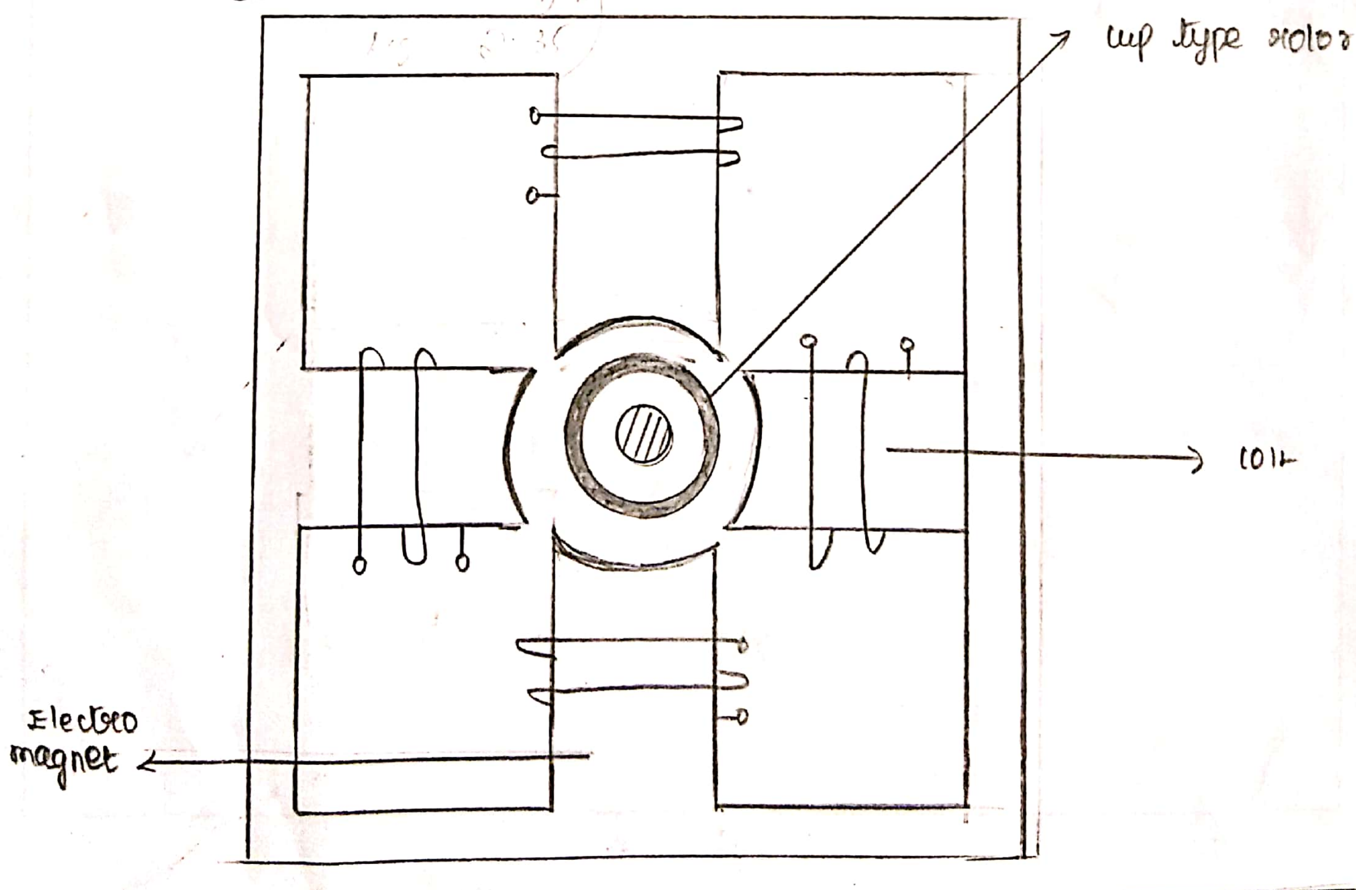
Construction.



The relay consists of four coils wound on the four poles of stator. These poles acts as a electromagnet when the coil is energised. The rotor has cup type structure.

Operating principle and Working.

It works on the principle of Ferraris measurement. At normal frequency, the impedances are in balance condition.

Thus the rotor does not experience any torque. But when frequency decreases the impedances vary hence imbalance condition occurs, and torque is applied on the rotor.

Thus the relay operates.

The relation between frequency and speed is given by

$$f = \frac{N_s P}{120}.$$

f: system frequency.

N_s: Synchronous speed

P = Number of poles.

Under speeding caused due to increment load leads to reduction of frequency.

The rate at which frequency decreases depends on overload percentage, variations in load and generator and the duration of overload on system.

III

UNIT-2

EE8601 Solid State drives

CONTROL RECTIFIER & CHOPPER FED DC MOTOR DRIVE

1: A 220V, 24 A, 1000 rpm, Separately Excited DC Motor, having an Armature resistance of 2Ω is Controlled by a chopper. The Chopping frequency is 500Hz and the I/p voltage is 230V. Calculate the duty ratio for a motor torque of 1.2 times rated torque at 500 rpm.

Solution:

$V_s = 220V, \; I_a = 24A, \; N_1 = 1000\,rpm, \; R_a = 2\Omega$

$f = 500Hz, \; V_s = 230V$

Back emf at 220V, $E_{b1} = V - I_a R_a$

$= 220 - (24 \times 2) = 172V$

Back emf at 500rpm $\frac{E_{b2}}{E_{b1}} = \frac{N_2}{N_1}$

$\frac{E_{b2}}{172} = \frac{500}{1000}$

$E_{b2} = 86V$

$T \propto I_a$

Here the Motor torque is 1.2 times of rated torque

$T_m = 1.2T$

$I_{am} = 1.2 I_a = 1.2 \times 24 = 28.8A$

$V_a = E_{b2} + I_{am} R_a = 86 + (28.8 \times 2) = 143.6V$

$V_a = \alpha V_s$

$\alpha = \frac{V_a}{V_s} = \frac{143.6}{230} = 0.624$

$\alpha = 0.624$

A 220V, 1500 rpm, 40A Separately Excited Motor with Armature Resistance of 0.5Ω is fed from 3φ Fully Controlled Rectifier. Available AC source has line voltage of 440V, 50Hz. Determine the value of Firing Angle (i) Motor is running at 1400 rpm and Half rated torque (ii) When motor running -800 rpm and rated torque

Solution:

$V = 220V$, $N_1 = 1500$ rpm, $I_a = 40A$, $R_a = 0.5$, $V_L = 440$

(i) Firing Angle when motor running at 1000 rpm and Half rated

Back emf at 1500 rpm

$$E_{b1} = V - I_a R_a = 220 - (40 \times 0.5) = 200V$$

Back emf at 1000 rpm

$$E_{b2} = \frac{N_2}{N_1} \times E_{b1} = \frac{1000}{1500} \times 200 = 133.33V$$

Half rated torque

$$I_a = \frac{40}{2} = 20A$$

$$V_a = E_{b2} + I_a R_a = 133.33 + 20 \times 0.25 =$$

Avg o/p of 3φ Full Converter

$$V_a = \frac{3V_{ml}}{\pi} \cos\alpha = \frac{3 \times \sqrt{2} \times 440}{\pi} \cos\alpha$$

$$\alpha = 76.04^\circ$$

(ii) Firing Angle when motor running at -800 rpm rated torque

$$E_{b2} = \frac{-800}{1500} \times 200 = -106.66V$$

$$V_a = E_{b2} + I_a R_a = -106.66 + (40 \times 0.5)$$

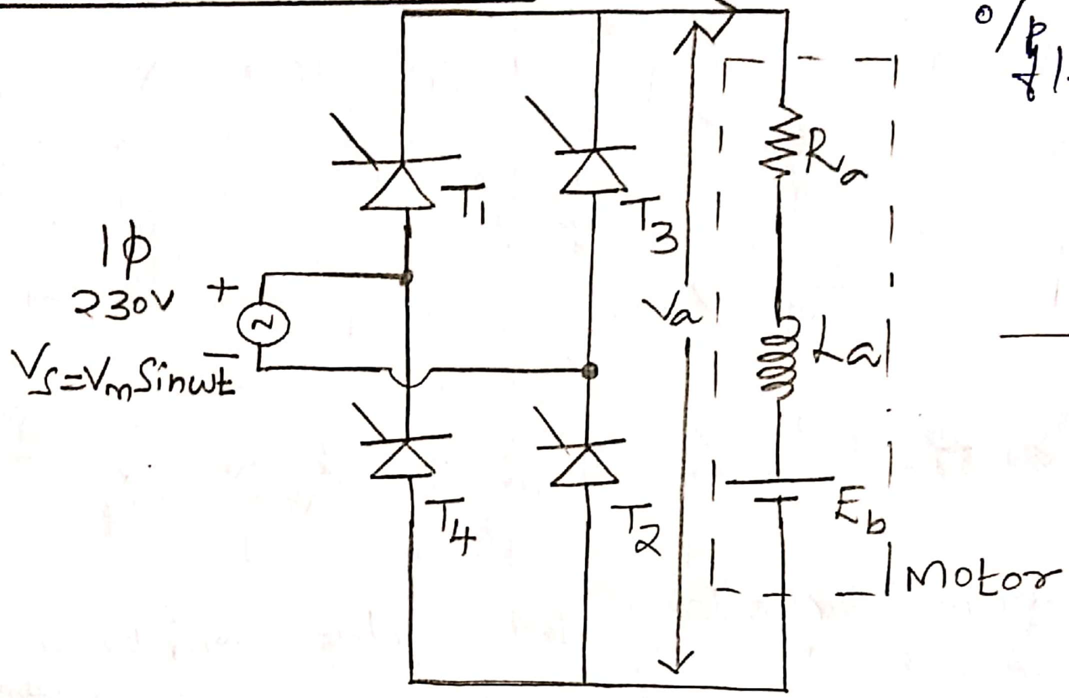
$$V_a = -86.66V$$

$$V_a = \frac{3V_{ml}}{\pi} \cos\alpha = -86.66$$

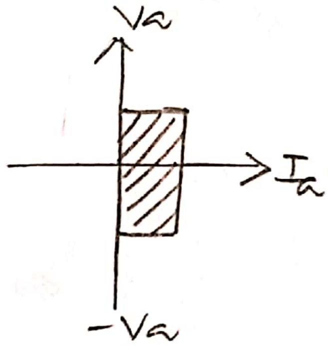
$$-86.66 = \frac{3 \times \sqrt{2} \times 440}{\pi} \cos\alpha$$

3. Input 1φ fully controlled rectifier fed DC drive (Connected to separately excited dc motor). It consist of 1φ, 230V, 50Hz supply, Four Thyristors $T_1 T_2 T_3 T_4$ & Separately Excited dc Motors R_a, L_a, E_b, I_a & V_a.

Continuous Conduction Mode:



O/p current (Armature I) flows continuously



Mode1: Positive Half cycle (α to $\pi+\alpha$)

$T_1 T_2$ ON, $T_3 T_4$ OFF

Current Flow

P(+) → T_1 → R_a → L_a → E_b → T_2 – N(-)

Inductance Stores Energy

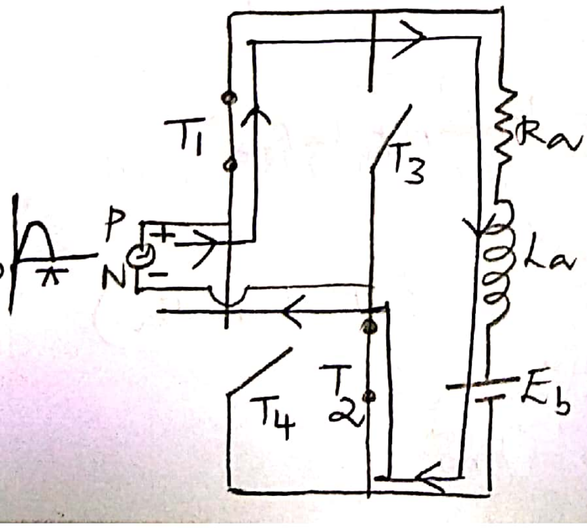
Mode2: Negative Half cycle ($\pi+\alpha$ to $2\pi+\alpha$)

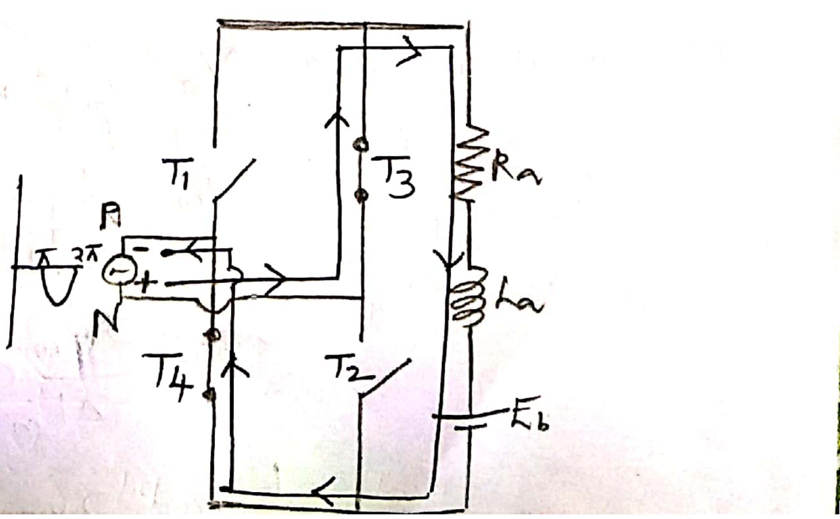
$T_3 T_4$ ON, $T_1 T_2$ OFF

Current flow

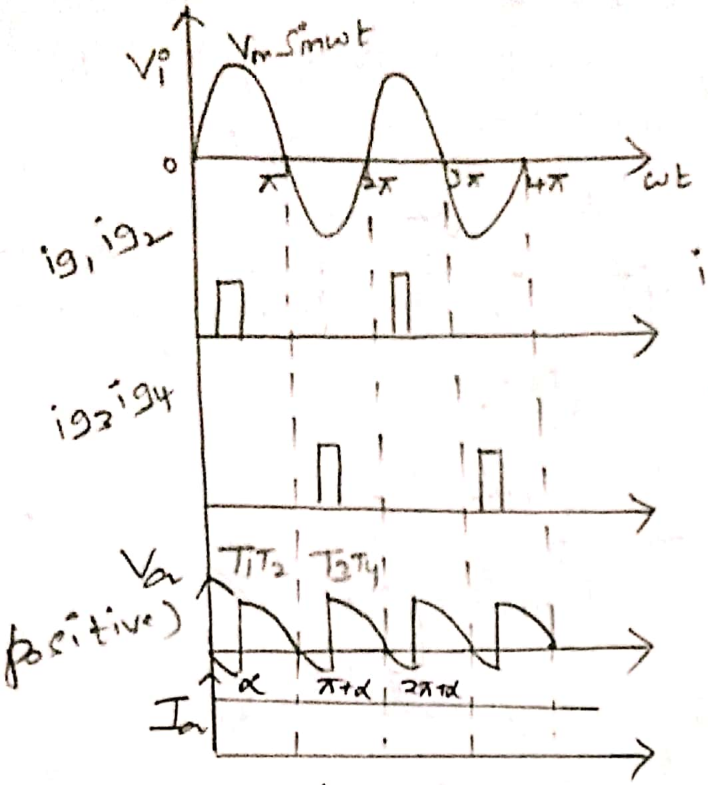
N(+) → T_3 → R_a – L_a – E_b → T_2 – P(-)

Inductance Stores Energy



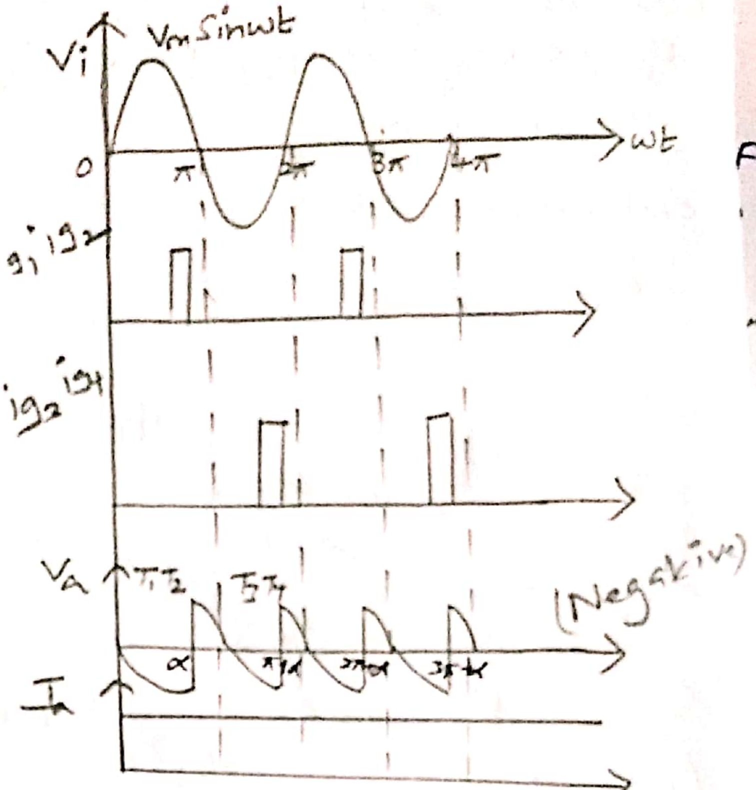


Rectification: ($\alpha < 90°$)



Power flow from source to Load

Inversion: ($\alpha > 90°$)



Power flow from Load to source

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

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

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

Avg o/p current $I_a = \frac{V_a - E_b}{R_a}$

$$V_a = E_b + I_a R_a = K_m \omega_m + I_a R_a$$

$$\omega_m = \frac{V_a - I_a R_a}{K_m}$$

$(T = K_m I_a)$

$$\omega_m = \frac{2V_m}{\pi K_m}\cos\alpha - \frac{I_a R_a}{K_m}$$

$$\omega_m = \frac{2V_m}{\pi K_m}\cos\alpha - \frac{T R_a}{K_m^2}$$

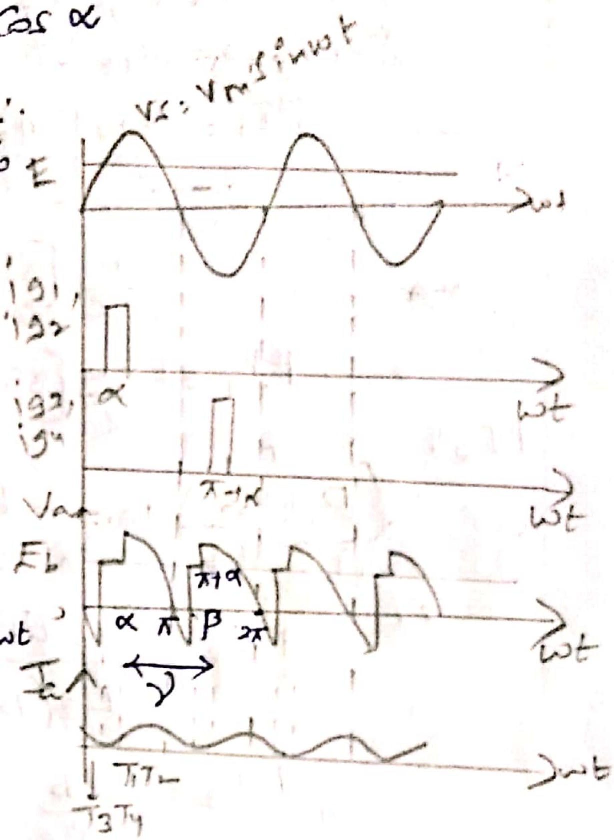
Rms Source Current $I_S = I_a$

Avg value Thyristor Current $I_{TA} = I_a/2$, Rms value of Thyristor Current $I_{TR} = \frac{I_a}{\sqrt{2}}$

I/p power $\cos\phi = \frac{2\sqrt{2}}{\pi}\cos\alpha$

Discontinuous Conduction Mode:

Armature Current doesn't flow Continuously.



α to $\beta \rightarrow T_1T_2$ ON, $V_a = V_s$

β to $\pi+\alpha \rightarrow T_1T_2$ OFF, $V_a = E_b$

$\pi+\alpha$ to $\pi+\alpha+\gamma \rightarrow T_3T_4$ ON, $V_a = V_s$

$\pi+\alpha+\gamma$ to $2\pi+\alpha \rightarrow T_3T_4$ OFF, $V_a = E_b$

$$V_a = R_a i_a + L_a \frac{di_a}{dt} + E_b = V_m \sin\omega t \quad (\alpha < \omega t < \beta)$$

$V_a = E_b$ and $i_a = 0$

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

÷ L_a both the sides

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

Complex function

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

$$\left(D + \frac{R_a}{L_a}\right) i_a = \frac{V_m \sin\omega t - E_b}{L_a}$$

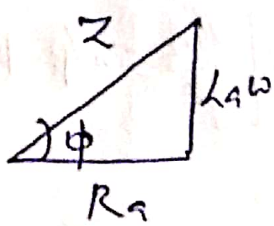
Using Complex function and Particular Integral

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

$$CF = C_1 e^{-\frac{R_a}{L_a}t}$$

$$= C_1 e^{-\frac{R_a \omega}{L_a \omega}t}$$

$$CF = C_1 e^{-\omega t \cot\phi}$$



$Z^2 = R_a^2 + L_a^2\omega^2$

PI_1:-

$$\left(D+\frac{R_a}{L_a}\right)i_a=\frac{V_m\sin\omega t}{L_a}$$

$$PI_1=\frac{V_m\sin\omega t}{L_a\left(D+\frac{R_a}{L_a}\right)}=\frac{V_m\sin\omega t\left(D-\frac{R_a}{L_a}\right)}{L_a\left(D^2-\frac{R_a^2}{L_a^2}\right)}$$

$$PI_1=\frac{V_m}{Z}\left[\frac{R_a}{Z}\sin\omega t-\frac{\omega L_a\cos\omega t}{Z}\right]$$

$$=\frac{V_m}{Z}\left[\sin\omega t\cos\phi-\cos\omega t\sin\phi\right]$$

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

PI_2:-

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

$$PI_2=\frac{-E_b}{L_a\left(D+\frac{R_a}{L_a}\right)}=\frac{-E_b}{L_a\times\frac{R_a}{L_a}\left(1+\frac{DL_a}{R_a}\right)}=\frac{-E_b}{R_a}\left(1+\frac{DL_a}{R_a}\right)$$

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

$i_a(\alpha)=0$, $\quad 0=C_1e^{-\alpha\cot\phi}+\frac{V_m}{Z}\sin(\alpha-\phi)-\frac{E_b}{R_a}$

$$C_1=-\left[\frac{V_m}{Z}\sin(\alpha-\phi)-\frac{E_b}{R_a}\right]e^{\alpha\cot\phi}$$

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

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

$i_a(\beta)=0$

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

Avg o/p voltage Va:

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

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

Avg o/p current:

$$I_a = \frac{V_a - E_b}{R_a}$$

Speed Equation (ω_m)

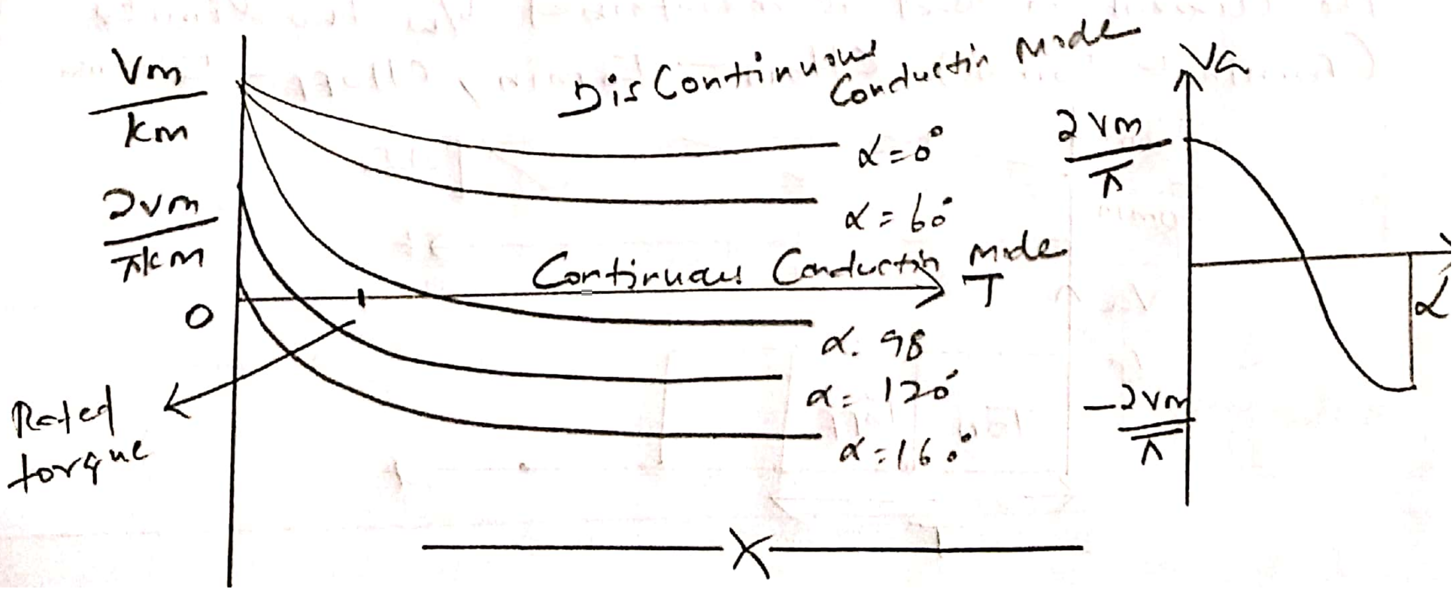
$$V_a = E_b + I_a R_a$$

$$E_b = k_m \omega_m$$
$$T = k_m I_a$$

$$\therefore k_m \omega_m + \frac{T}{k_m} R_a = \frac{V_m}{\pi}(\cos\alpha - \cos\beta) + \frac{(\pi+\alpha-\beta)}{\pi} k_m \omega_m$$

$$\omega_m = \frac{V_m}{k_m} \frac{(\cos\alpha - \cos\beta)}{(\beta-\alpha)} - \frac{T}{k_m^2} R_a \left[\frac{\pi}{\beta-\alpha}\right]$$

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



4. Control Strategies:

The Avg o/p voltage can be controlled through (δ) duty cycle, by opening & closing the semiconductor switch.

1. Time Ratio Control (TRC)
2. Current limit Control (CLC)

Time Ratio Control:

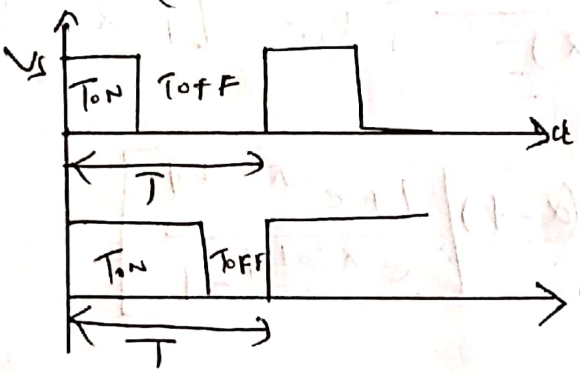
TRC, the value $\frac{T_{ON}}{T}$ is varied,

① Constant Frequency system
② Variable frequency system

Constant Frequency System:

In this control method, the ON time period is varied (T_{ON}) chopping frequency is kept constant.

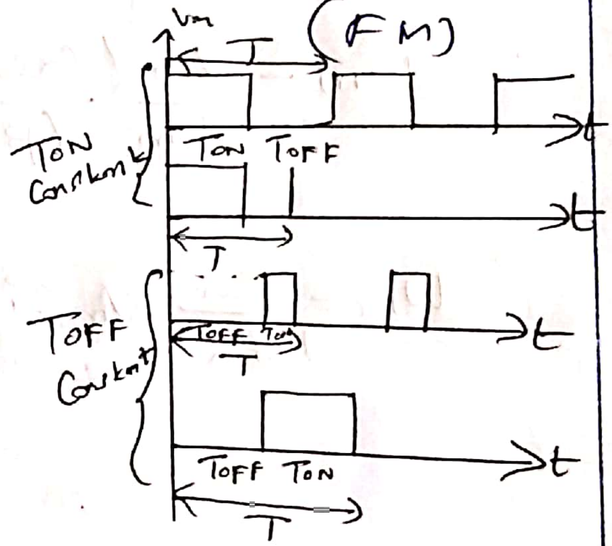
(PWM)



Variable Frequency System

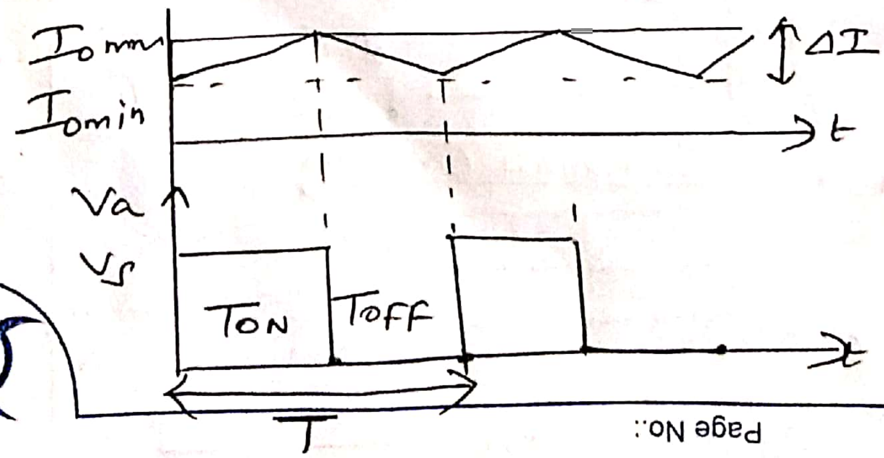
TON is made constant
TOFF is made constant

(FM)



Current limit Control:

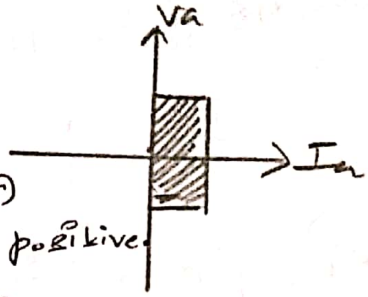
The chopper is switched ON and OFF so that the current in load is maintained b/w two limits (I_{omin} to I_{omax}) CH ON — I_o min, CH OFF — I_o max

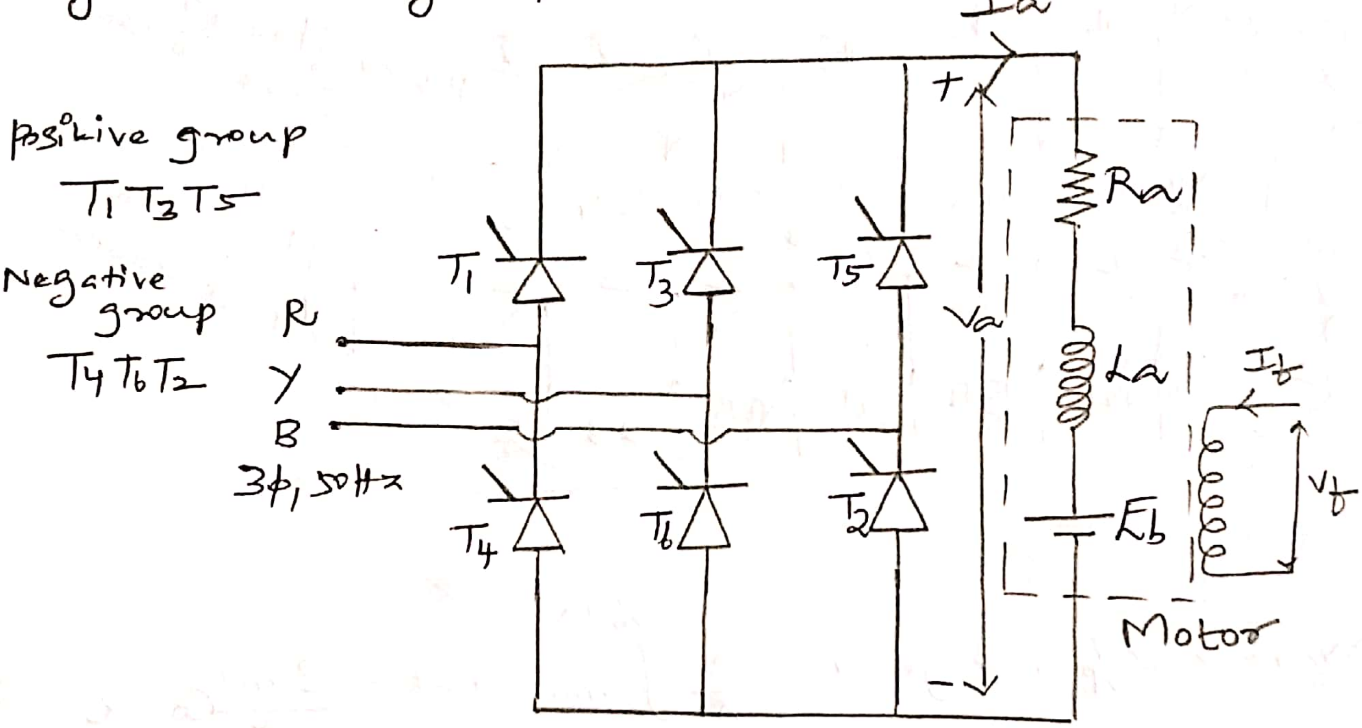


3ϕ Fully Controlled Converter:

5. 3ϕ Full Converters used in Industrial Applications upto 1500kW.

The two quadrant Converter, Average o/p voltage is either positive (or) Negative but Avg output Current is always positive.





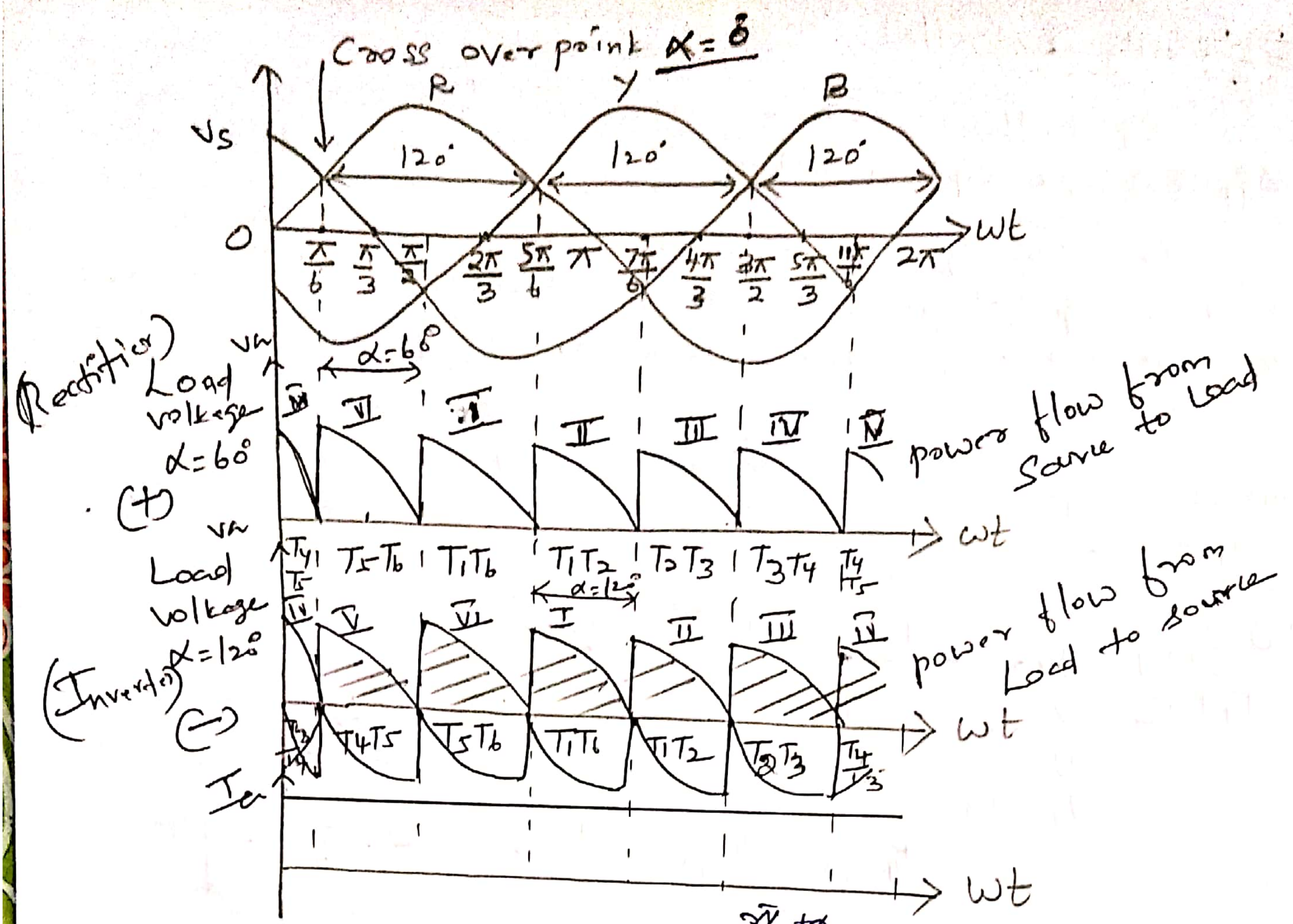
Mode :	Supply	TON	TOFF
1	R(+) Y(-)	$T_1 T_6$	Remaining thyristor
2	R B	$T_1 T_2$	
3	Y B	$T_2 T_3$	
4	Y R	$T_3 T_4$	
5	B R	$T_4 T_5$	
6	B Y	$T_5 T_6$	

Rectification Mode :

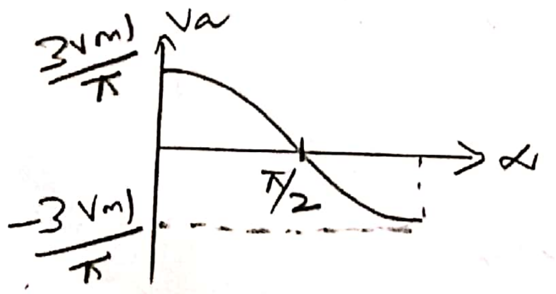
$\alpha = 60°$, Every 60° interval each pair of Thyristors Conducted to turn ON, Here (power flow from Source to Load)

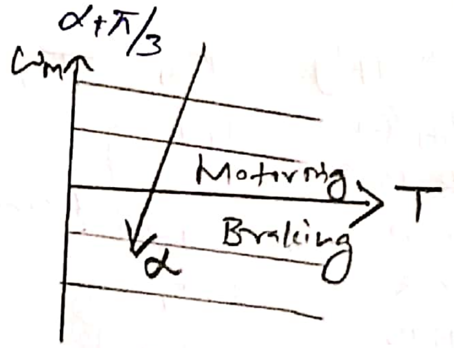
Inversion Mode :

$\alpha = 120°$, Every 60° Interval each pair of Thyristor Conducted to turn ON, (power flow from Load to Source)



Average o/p voltage $V_a = \frac{3}{\pi}\int_{\alpha+\pi/3}^{2\pi/3+\alpha} V_{ml}\sin\omega t = \frac{3V_{ml}}{\pi}\cos\alpha$





$V_a = E_b + I_a R_a = k_m \omega_m + I_a R_a$

$\omega_m = \frac{V_a - I_a R_a}{k_m}$, $T = k_m I_a$

$\omega_m = \frac{V_a}{k_m} - \frac{R_a}{(k_m)^2} T$

Rms value of Source I, $I_{rms} = I_a\sqrt{2/3}$

Rms value of Thyristor I, $I_{TR} = I_a\sqrt{1/3}$

Avg value of Thyristor I, $I_{TA} = I_a/3$

I/p PF $= \frac{V_a I_a}{\sqrt{3} V_s I_{rms}}$

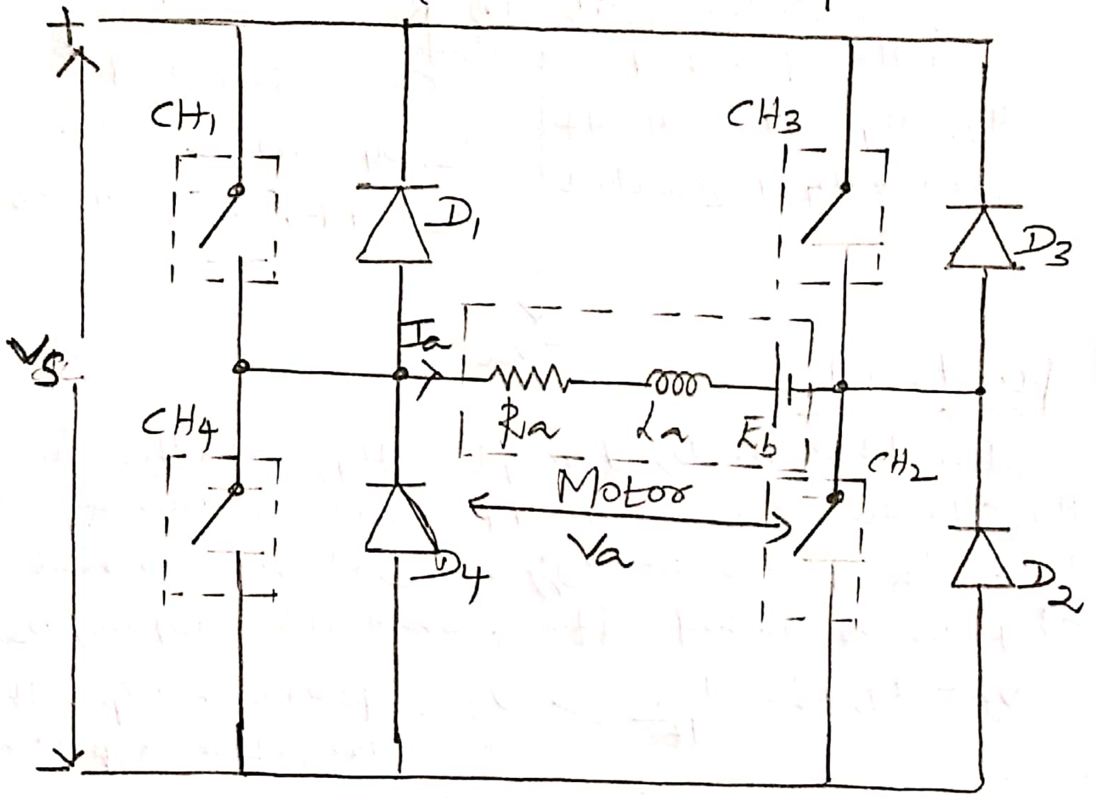
Four Quadrant DC - DC Converter:

6. Four Quadrant chopper (or) Type E chopper, Four semiconductor switches CH1 to CH4 & four Diodes D1 to D4 in antiparallel.

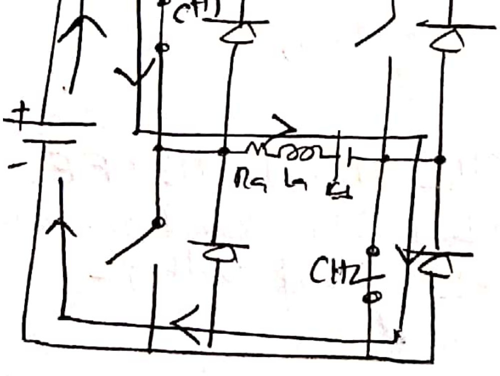
Ist Quadrant:

CH1 is operated with CH2 ON and CH3 & CH4 OFF. When CH1 and CH2 are kept ON, Load current starts to flow from Load to source and voltage appears across Load is equal to source voltage. ($V_a = V_s$)

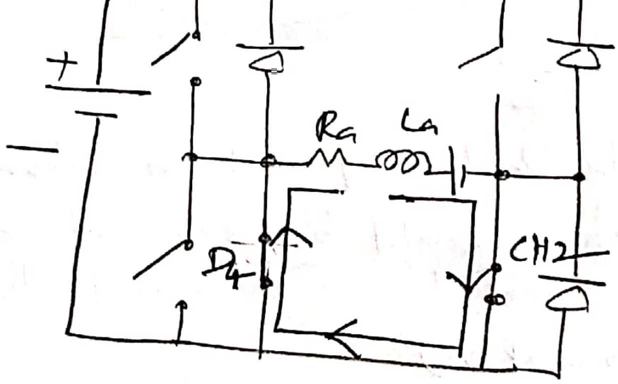
Main circuit diagram



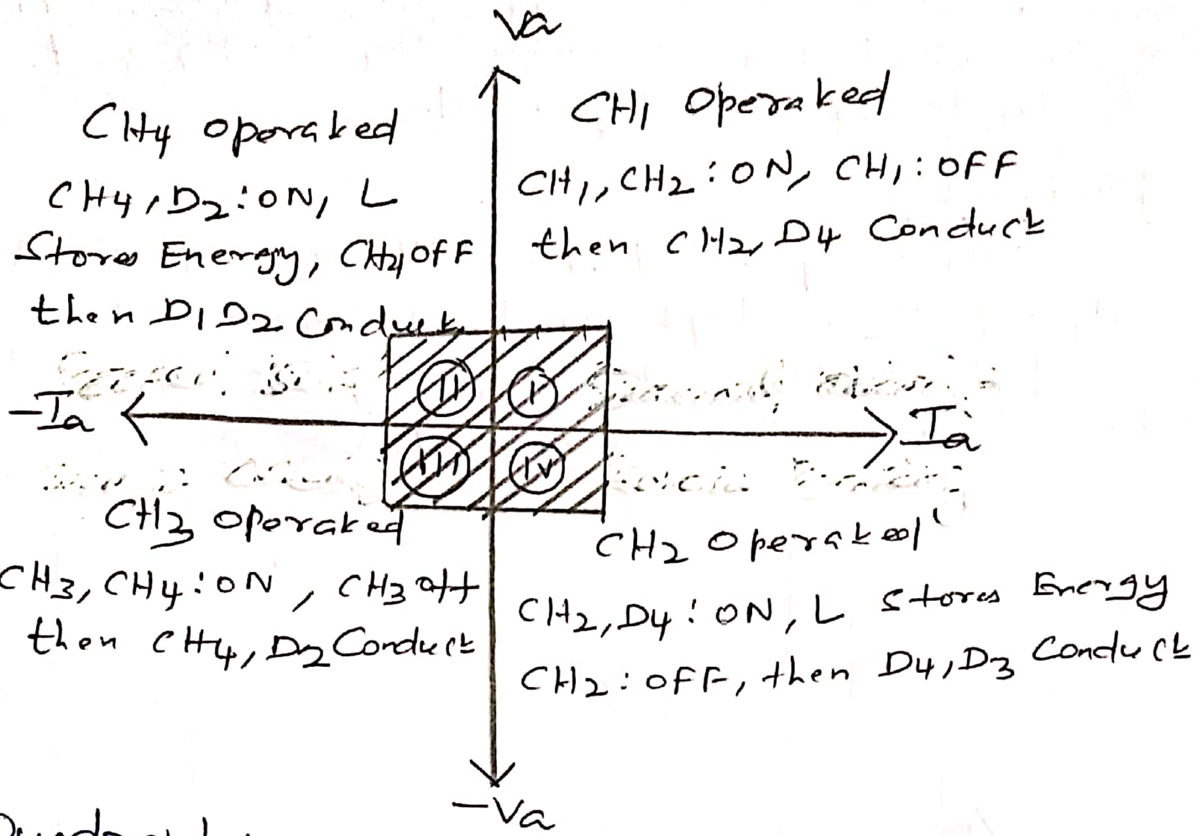
And then CH1 OFF and CH2 ON, Free wheeling action takes place through CH2 and D4, Direction of current is positive during both ON and OFF conditions of CH1 (V_a & I_a positive)



CH1, CH2



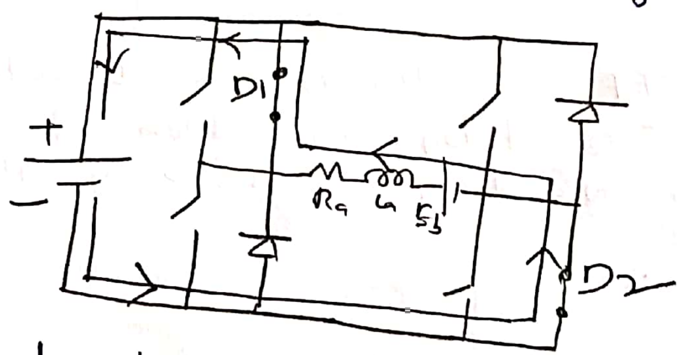
CH2, D4



2nd Quadrant :

In this mode, Except CH4, all other switches CH1 CH2 CH3 are remain in OFF position, During CH4 ON, Inductance La Stores Energy, negative current CH4, La, D2, Eb. When CH4 is switched off. Current flow D1 and D2.

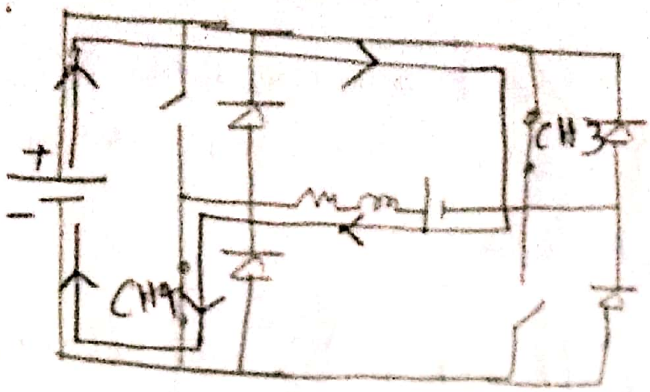
$$V_a = E_b + L_a \frac{di_a}{dt} > V_s$$, positive o/p voltage, Negative o/p Current

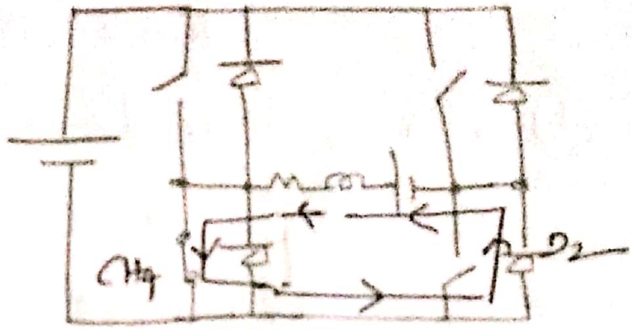


3rd Quadrant :

CH3 is Under operation with CH4 ON and CH2 OFF, The load emf should be reversed so that the load current flows from Load to Source and also the Load voltage (Va and Ia Negative)

CH3 is turned OFF, Negative Load starts to freewheel through Diode D2 and CH4

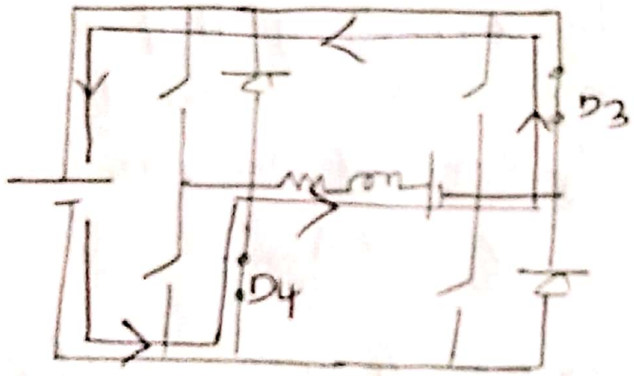




Four Quadrant :-

CH1, CH3, CH4 kept OFF and CH2 is operated. The polarity of Load emf should be Reversed, CH2 ON Inductor L gets charged due to flow of positive current through CH2, D4, La and Eb.

D3 and D4 ON, o/p voltage is negative but having positive Load Current (Va negative & Ia positive)



7. A 200V, 1000 RPM, 10A a separately Excited dc motor has an Armature Resistance of 1Ω, It's fed from a 1ϕ Full Converter with an Ac Source voltage of 230V, 50Hz. Assume Continuous Conduction, Compute (i) Firing Angle for rated motor torque at 500rpm (ii) Firing Angle half rated of torque at (-500 rpm) (iii) Motor speed for $\alpha = 150°$ and Half rated torque.

Solution:

Under rated Conditions of the Motor

$$V_a = E_b + I_a R_a = k_m W_m + I_a R_a$$

$$200 = k_m \times \left(\frac{2\pi \times 1000}{60}\right) + (10 \times 1)$$

$K_m = 1.814$ V-s/rad (or) 1.814 Nm/A

(i) Firing angle for rated motor torque at 500 rpm

$V_a = K_m W_m + I_a R_a$

$$\frac{2\sqrt{2} \times 230}{\pi} \cos\alpha = \left[1.814 \times \frac{2\pi \times 500}{60}\right] + (10 \times 1)$$

$\therefore \alpha = 59.53°$

(ii) Firing Angle for Half rated motor torque (-500)

$$\frac{2\sqrt{2} \times 230}{\pi} \cos\alpha = \left[\frac{1.814 \times 2\pi \times (-500)}{60}\right] + (5 \times 1)$$

$\therefore \alpha = 115.75°$

(iii) Motor Speed for $\alpha = 150°$ and Half rated torque

Half rated torque, Motor Armature Current

$= \frac{1}{2} \times$ rated Armature Current

$I_a = 10/2 = 5A$

$$\therefore \frac{2\sqrt{2} \times 230}{\pi} \cos 150° = (1.814 \times W_m) + (5 \times 1)$$

$W_m = -101.61$ rad/s

Speed $N = \frac{-101.61 \times 60}{2\pi} = -970.3$ rpm

———— x ————