

Thyristor

DATE - 31/07/19

①

Thyristor family → triac, diac, silicon controlled switch, programmable unijunction transistor (PUT), GTO, RCT etc.

↳ one of the added member

silicon controlled Rectifier

↳ is called because silicon is used for its construction and it operates as a rectifier and can be used

Thyristor → proper device

↳ THYRISTOR + TRANSISTOR

That means thyristor is a solid state device like transistor and has characteristics similar to that of a thyatron tube.

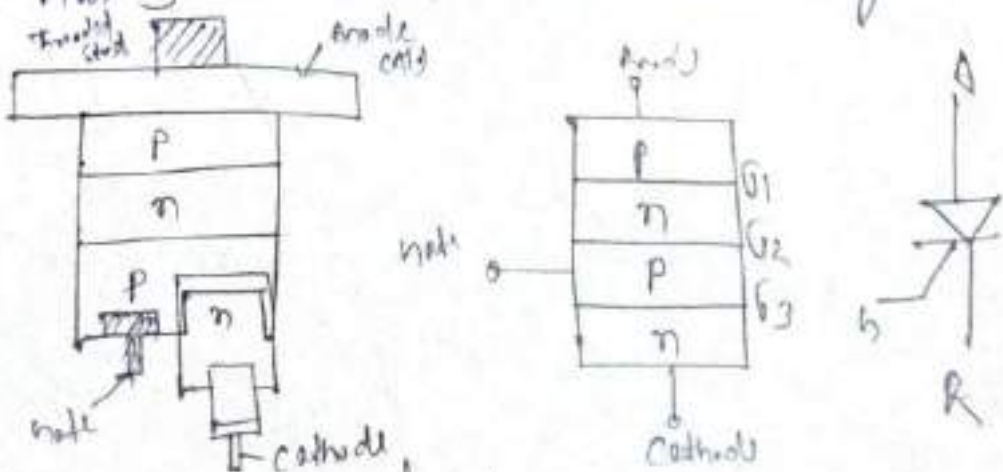
Thyristor

(1) It constitute three p-n junctions

(2) It has two stable states, an ON state & an OFF state and can change its state from one to another.

→ Thyristor is a four layer, 3 junction p-n-p-n semiconductor switching device.

→ It has 3 terminals; anode, cathode & gate.



↳ The threaded portion is for the purpose of tightening the thyristor to the frame or heat sink with the help of a nut.

Gate terminal is usually kept near cathode terminal. (2)

Outer p region \rightarrow Anode

Outer n region \rightarrow Cathode

Inner p region \rightarrow Gate

Rating

SCR of voltage rating 100V and an rms current rating of 3000A with corresponding power handling capacity of 300W are available

\rightarrow Such a high power thyristor can be switched on by a low voltage supply of about 10V and this gives an idea of the immense power amplification capability (5000⁶) of the device

\rightarrow Because of these useful features, SCR is almost universally employed these days for all high power controlled devices

\rightarrow Like diode, an SCR is an uni-directional device that blocks the current from cathode to anode. Unlike diode, a thyristor also blocks current from anode to cathode until it is triggered into conduction by a proper gate signal b/w gate & cathode

Static IV characteristics of thyristor

An elementary circuit diagram for obtaining static IV characteristics of a thyristor is shown below

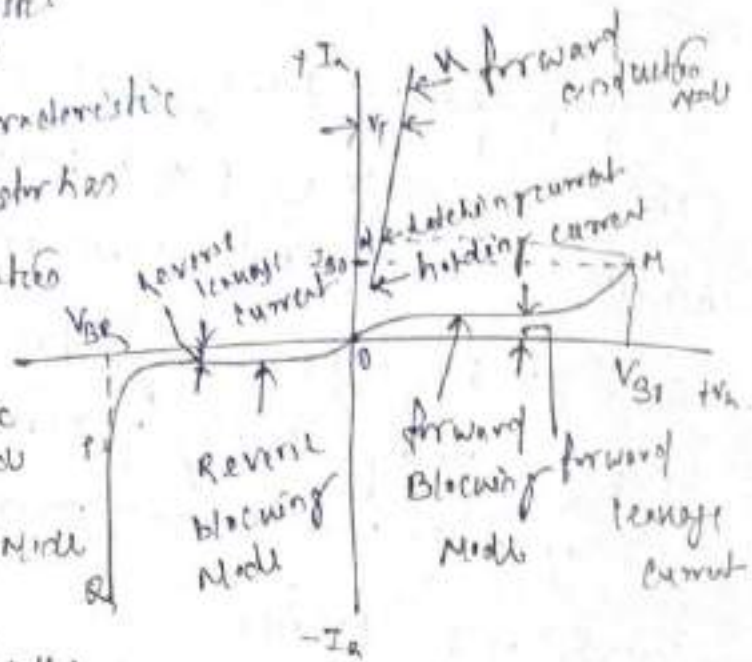


The anode and cathode are connected to main source along with. The gate and cathode are connected to main source fed from a source which provides +ve gate current from gate to cathode.

Static V-I characteristics

→ Typical I_C - I_A - V characteristic reveals that a thyristor has 3 basic mode of operation namely.

- (i) Reverse blocking mode
- (ii) Forward blocking mode
- (iii) Forward conduction mode



Reverse blocking Mode:

When cathode is made +ve w.r.t anode with switch open, thyristor is reverse biased.

∴ $V_1, V_3 \rightarrow$ Reverse biased
 $V_2 \rightarrow$ Forward biased.

→ This device behaves as if two diodes are connected in series with reverse voltage applied across them.

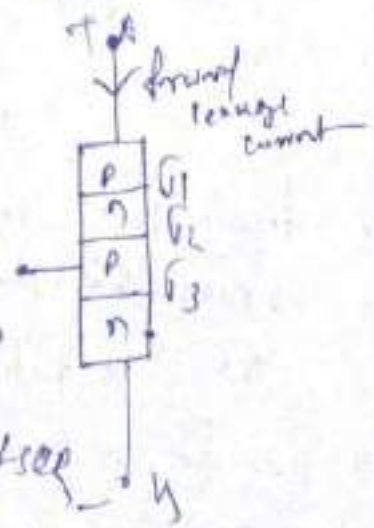
→ A small leakage current of the order of few microamperes.

→ This is reverse blocking mode, called off-state of thyristor.

- If the reverse voltage is increased, then at a critical breakdown level called reverse breakdown voltage V_{BR} , an avalanche occurs at V_{BR} and the reverse current increases rapidly.
- A large current associated with V_{BR} gives rise to more losses in the SCR which leads to damage of SCR.
- So SCR in the reverse blocking mode is therefore treated as open switch.
- Note that IV characteristic after avalanche breakdown during reverse blocking mode is applicable only when load resistance is zero.

Forward blocking Mode:

- When anode is positive w.r.t cathode with gate cut open thyristor is said to be forward biased
- V_1 & $V_3 \rightarrow$ forward biased
 $V_2 \rightarrow$ reverse biased



- In this mode small current called I_{G0} forward leakage current flows.
- ON represents forward blocking mode of SCR.
- As forward leakage current is small, SCR after a high impedance. Therefore it can be treated as an open switch even in the forward blocking mode.

Forward conduction mode

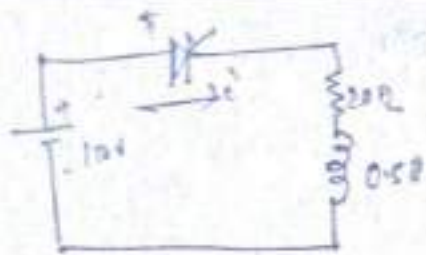
(5)

When anode to cathode forward voltage is increased with gate cut open, reverse bi junction J_2 will have avalanche breakdown at a voltage called forward breakover voltage V_{BO} .

- After this breakdown thyristor gets turned on with point M at once shifting to N and then to point anywhere b/w N & M .
- Here NM represents forward conduction mode.
- A thyristor can be brought from forward blocking mode to forward conduction mode by turning it on by applying (i) a +ve gate pulse b/w gate & cathode or (ii) a forward breakover voltage across anode and cathode.
- Forward conduction mode NM shows that voltage drop across thyristor is of the order of 1 to 2V depending upon the current.
- In forward conduction mode thyristor is treated as closed switch.

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- (6) The latching current of thyristor cat in fig (2) is some. The duration of firing pulse is chosen such that thyristor get latched.



(6)

$$i = \frac{V}{R} (1 - e^{-t/\tau}) \quad (\text{current in } R \text{ (cut)})$$

$$\tau = L/R = \frac{0.5}{200} = \frac{5}{200} = 0.025 \text{ sec}$$

$$i(0.1) = \frac{10}{200} (1 - e^{-40000.025})$$

$$50 \text{ mA} = 5 (1 - e^{-40000.025})$$

$$10 \text{ mA} = (1 - e^{-t/0.025})$$

$$e^{-t/0.025} = 1 - 0.010$$

$$-t/0.025 = \ln(0.99)$$

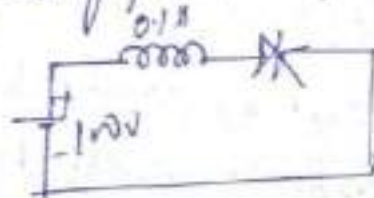
$$t/0.025 = 0.01$$

$$t = 0.01 \times 0.025$$

$$= 250 \mu\text{sec}$$

so SCR will not turn on.

0.2.2 The latching current in the cut shown below is 4mA. Obtain the minimum width of the gating pulse required to properly turn on the SCR.



$$V = L \frac{di}{dt}$$

$$L \frac{di}{dt} = V$$

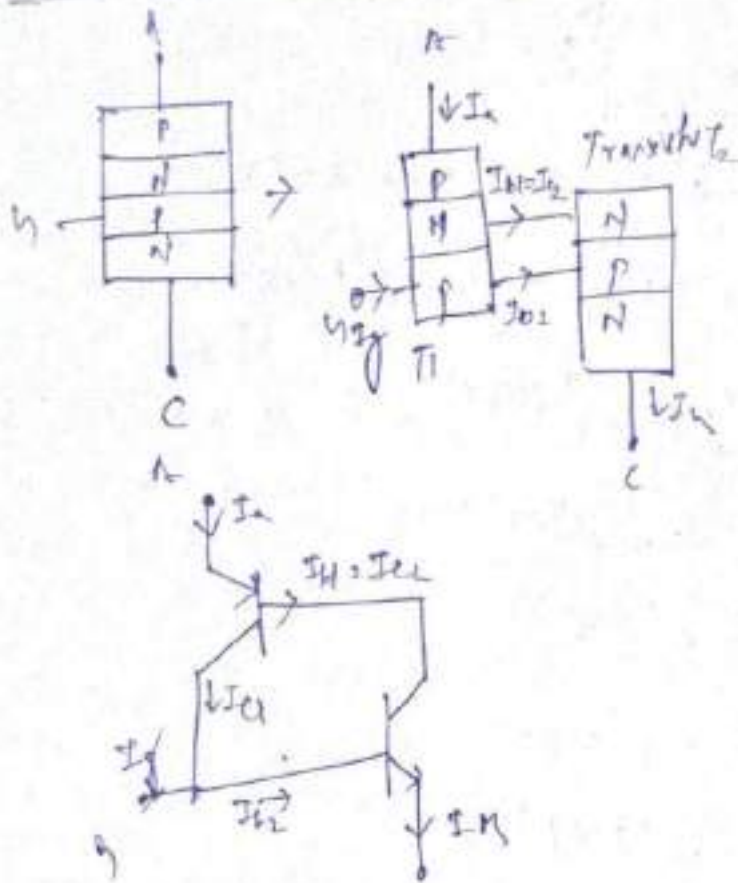
$$\int di = \int \frac{V}{L} dt$$

$$0.04 = \frac{V}{L} t$$

$$4 \text{ mA} = \frac{10}{100} \times t \Rightarrow t = \frac{0.004 \times 100}{10} = 4 \mu\text{sec}$$

Two transistor model of SCR

(7)



It is observed from the figure that the collector current of transistor T_1 becomes the base current of T_2 .

$I_{C1} = I_{B2} = I_{E2}$ $\alpha_1 = \text{PNP transistor}$
 = emitter current of T_2 + total current

I_A, I_{E1}, I_C

$$I_{E1} = \alpha_1 I_A + I_{CBO1}$$

where α_1 = common base current gain of α_1

I_{CBO1} = common base leakage current of α_1

Similarly for α_2 , the collector current I_{C2} is given by

$$I_{C2} = \alpha_2 I_{E1} + I_{CBO2}$$

α_2 = common base current gain of α_2

I_{CBO2} = common base leakage current of α_2 .

$I_{E2} = I_{C1}$ = emitter current of α_2

$$I_c = I_{c1} + I_{c2} \quad (8)$$

$$I_c = \alpha_1 I_a + I_{cB1} + \alpha_2 I_y + I_{cB2}$$

When gate current is applied then $I_y = I_c + I_g$

Substituting the value of I_y in above

$$I_c = \alpha_1 I_a + I_{cB1} + \alpha_2 (I_c + I_g) + I_{cB2}$$

$$I_a = \frac{\alpha_2 I_g + I_{cB1} + I_{cB2}}{1 - (\alpha_1 + \alpha_2)}$$

Assuming the leakage current of transistor T_1 & T_2 to be negligible small, we have

$$I_c = \frac{\alpha_2 I_g}{1 - (\alpha_1 + \alpha_2)}$$

If $(\alpha_1 + \alpha_2) \rightarrow 1$ \Rightarrow the value of anode current I_c i.e. anode current suddenly attains a very high value approaching infinity i.e. the device suddenly latches into conduction and state from the non-conduction state \rightarrow This characteristic of device is known as regenerative action.

Turn on Method of a thyristor

① Forward voltage triggering

\rightarrow When anode to cathode forward voltage is increased with gate cut open, the reverse biased junction J_2 will have an avalanche breakdown at a voltage called forward breakover voltage V_{BO} . At this voltage a thyristor changes from off state to on state.

(b) Temperature triggering

(9)

Like any other semiconductor, the width of depletion layer of thyristor decreases on increasing the junction temperature.

- Thus in a thyristor when the voltage applied b/w the anode and cathode is very near to breakdown voltage, the device can be triggered by increasing its junction temp.
- By increasing the temperature to a certain value, a situation arises when the reverse biased junction collapses making the device conduct. This is also known as thermal triggering.

(c) Light triggering (Optical triggering)

- In this method, as the name suggests, the energy is imparted by radiation. Thyristor is bombarded by energy particle such as electrons or photons.
- With the help of external energy, electron-hole pairs are generated in the device, thus increasing the no. of charge carriers. This leads to instantaneous flow of current within the device and the triggering of the device.

(d) dv/dt triggering

- With forward voltage across anode and cathode of a device the junction J_1 is forward biased and where as junction J_2 becomes reverse biased.
- This reverse biased junction J_2 has the characteristics of a capacitor due to charge existing across the junction.
- If a forward voltage is suddenly applied, a charging current will flow tending to turn the device on.

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if the voltage impressed across device is V and the charge is q and the capacitance is C .

then
$$i_c = \frac{dq}{dt} = \frac{q}{C \cdot V} = C \frac{dV}{dt} + V \frac{dC}{dt}$$

$$\Rightarrow \boxed{i_c = C \frac{dV}{dt}}$$

Therefore, if rate of change of voltage across the device is large, the device may turn on even though the voltage appearing across the device is small.

3) Gate triggering

- This is most commonly used method for triggering SCR.
- By applying a +ve signal at the gate terminal of the device, it can be triggered much before the specified breakover voltage.
- The conduction period of the SCR can be controlled by varying the gate signal with in the specified values of maximum & minimum gate current.
- For gate triggering, a signal is applied between gate & cathode of the device. Three types of signals can be used for this purpose which are either DC signal, pulse signal or AC signal.

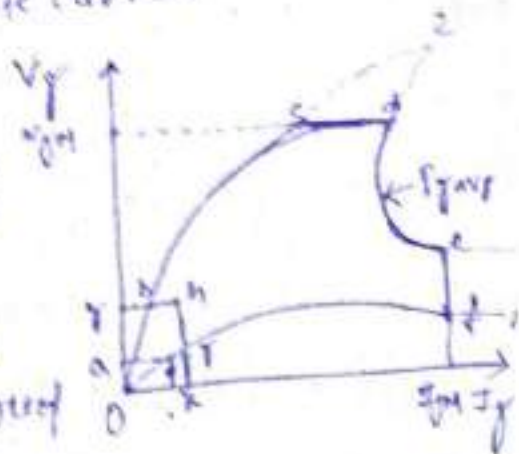
Thyristor Gate Characteristics:

→ The forward gate characteristic of thyristor is a graph between gate voltage and gate current.

→ The gate trigger circuitry must be suitably designed to take care of unavoidable scatter of characteristic.

→ Curve-1 represents the lowest voltage value that must be applied to turn on the SCR.

→ Curve-2 gives the highest possible voltage values that can be safely applied to gate circuit.



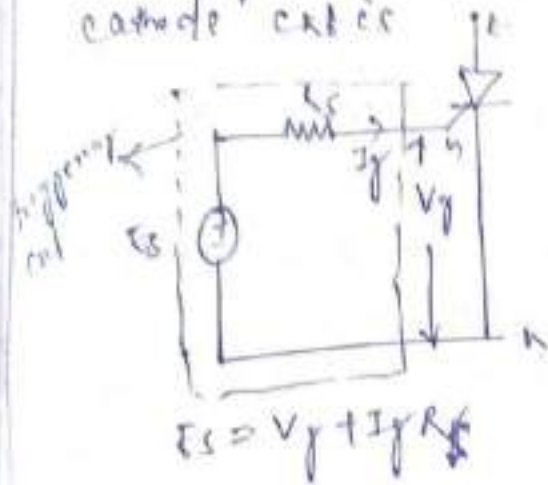
→ Each thyristor has maximum limit V_{gM} for gate voltage and I_{gM} for gate current. There is also rated (avg) gate power dissipation P_{gav} specified for each thyristor. These limits should not be exceeded in order to avoid permanent damage of G_2 .

→ There are also minimum limits for V_g & I_g for reliable turn on; these are represented by V_{g1} and I_{g1} respectively.

→ A non-triggered gate voltage is also prescribed by the manufacturer of SCR. This is indicated by V_{g0} .

→ If firing circuit generates the gate signal prior to the desired instant of triggering of SCR, it should be ensured that this unwanted signal is less than the non-triggered gate voltage V_{g0} . At the same time, all noise signals should be less than voltage V_{g0} .

The firing circuit which is used to feed power to gate cathode circuit (13)

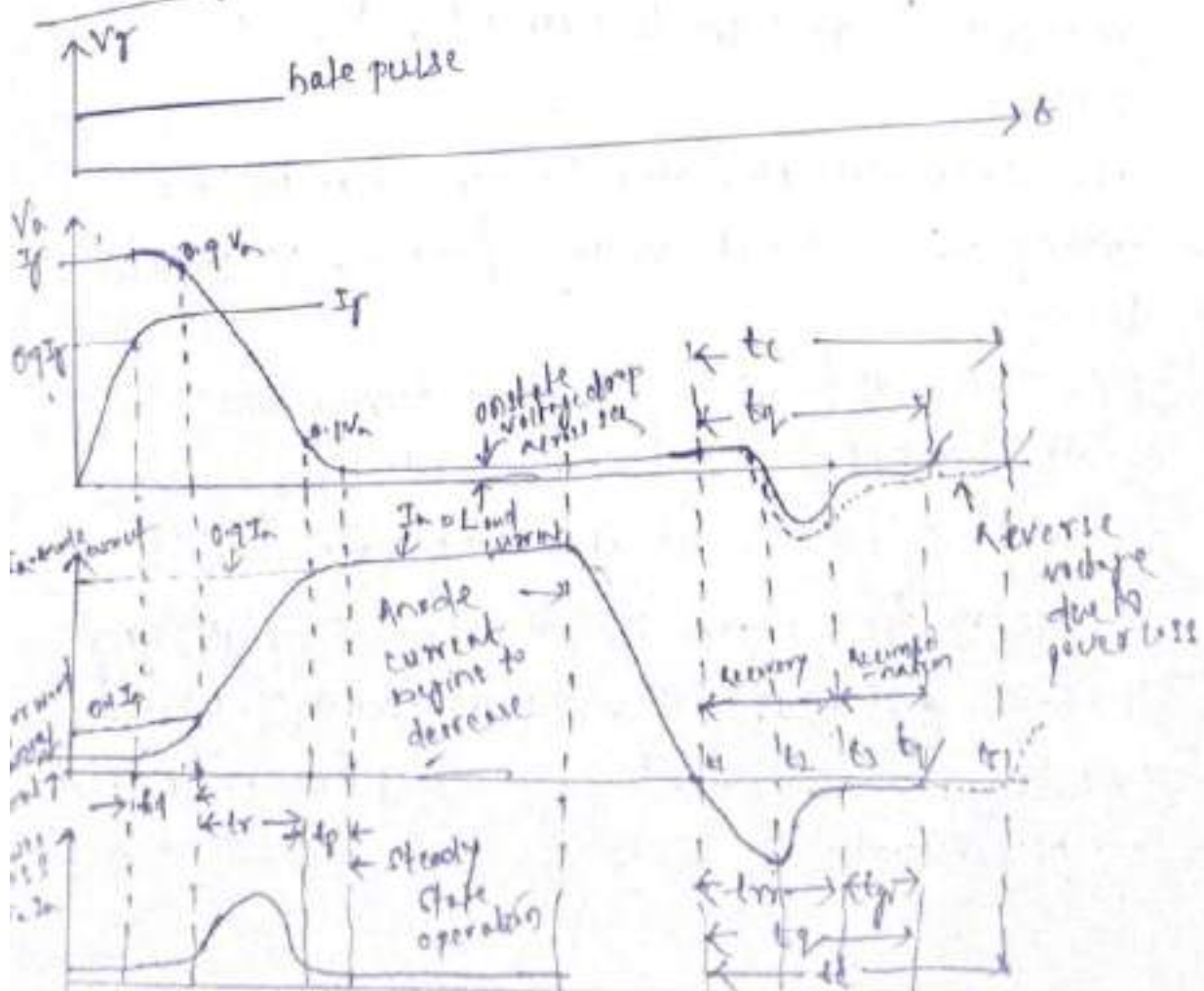


where E_s = gate source voltage
 V_g = gate cathode voltage
 I_g = gate current
 R_g = gate source resistance

Switching characteristics of thyristor:

The time variations of the voltage across the thyristor and the current through it during turn on & turn off process give the dynamic or switching characteristic of thyristor.

Switching characteristic



switching characteristics during turn on

(15)

- A forward biased thyristor is usually turned on by applying a +ve gate voltage between gate & cathode. There is however a transition time forward off state to forward on state.
- This transition time called thyristor turn on time, & is defined as the time during which it changes from forward blocking state to forward on state.
- Total turn on time can be divided into three intervals
(i) Delay time t_d
(ii) Rise time t_r
(iii) Spread time t_p

(i) Delay time

- The delay time is measured from the instant at which gate current reaches $0.9 I_g$ to the instant at which anode current reaches to $0.1 I_a$.
- The delay time may also be defined as the time during which anode voltage falls from V_a (initial) to $0.9 V_a$.
- It's also defined as the time during which anode current rises from forward leakage current to $0.1 I_a$ where I_a is final value of anode current.
- The delay time can be decreased by applying a high gate current and more forward voltage between anode & cathode. The delay time is fraction of microsecond.

(i) Rise time (tr)

(14)

- The rise time t_r is the time taken by anode current to rise from $0.1 I_a$ to $0.9 I_a$.
- On rise time ~~anode voltage~~ forward blocking off state voltage fall from 0.9 to 0.1 of its initial value.
- The rise time is inversely proportional to magnitude of gate current and its build up rate. Thus t_r can be reduced if high and steep current pulses are applied to gate.
- The main factor determining t_r is the nature of anode circuit.
ex for RL cat t_r is high while for RC circuit t_r is low.
- During rise time turn on losses in the thyristor are highest due to high anode voltage and large anode current.

(ii) Spread time (t_{sp})

- It is the time taken by the anode current to rise from $0.1 I_a$ to I_a & the forward blocking voltage fall from 0.1 of its initial value to the on state voltage drop (1 to 1.5V).
- During this time conduction spreads over entire cross section of the cathode of SCR.
- The spreading time depends upon the area of cathode & on gate structure of SCR.

$$t_{on} = t_{tr} + t_{sp} + t_p$$

- (15)
- The magnitude of gate current is usually 3 to 5 times minimum gate current required to trigger an SCR.
 - When gate current is several times higher than minimum gate current required, then the thyristor is said to be hard fired or overdriven.
 - Hard firing or overdriven thyristor reduces its turn on time and enhances its di/dt capabilities.

switching characteristic during turn off:

- Thyristor turn off means that it has changed from on state to off state and is capable of blocking the forward voltage. This dynamic process of the SCR from conduction state to forward blocking state is called commutation process or turn off state.
- The turn off time t_{off} of a thyristor is defined as the time b/w the instant the anode current becomes zero and the instant SCR regains forward blocking capability.
- During turn off time, all the excess carriers from the four layers of SCR regions must be removed. This removal of excess carriers consists of sweep out of holes from outer p-layer and e^- from outer n-layer. The carriers around G_2 can be removed only by recombination.

(16)
turn off time = Reverse Recovery time of gate recovery time
(t_{rr}) (t_{gr}) (t_{pr})

- Thyristor with slow turn off time (50-100 μ sec) are called converter grade SCR and those with fast turn off time (3-50 μ sec) called inverter grade SCR.
- Converter grade SCRs are cheaper and are used for slow turn off process as in phase control of rectifier, ac voltage controller, cyclo-converter etc.
- Inverter grade SCRs are costlier and are used in inverters, choppers and force commutated converters.

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Turn off Methods of Thyristor

- Turn off a thyristor means bringing the device from forward conduction state to forward blocking state.
- For successful turn off (i) its anode current falls below the holding current (ii) & a reverse voltage is applied to thyristor for a sufficient time to enable it to recover to blocking state.
- Simply commutation means process of turning off a thyristor.
- Commutation is basically two types
(i) Natural commutation (line commutation)
(ii) forced commutation.

① Natural commutation (Line commutation) (17)

→ If the nature of the supply supports the commutation process then it is known as natural commutation.

- Ex
- (i) Rectifier (AC to DC)
 - (ii) AC voltage controller (AC to AC)
 - (iii) Step down cyclo converter (AC to AC)

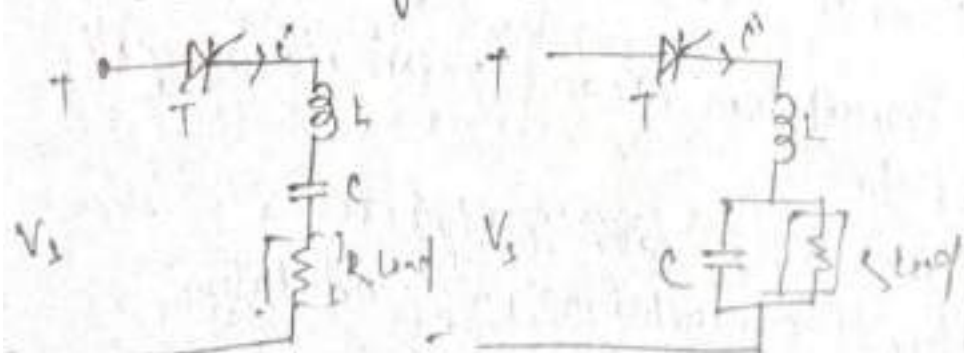
② forced commutation:

→ DC supply will not support the commutation process, therefore we must use a forced commutation circuit to turn off SCR, if load commutation is not possible.

- Ex
- (i) Chopper (DC to DC)
 - (ii) Inverter (DC to AC)
 - (iii) Step up cycloconverter (AC to AC)

③ Class-A commutation / Load commutation / Resonant commutation

→ for achieving load commutation of a thyristor the commutating component L & C are connected as shown



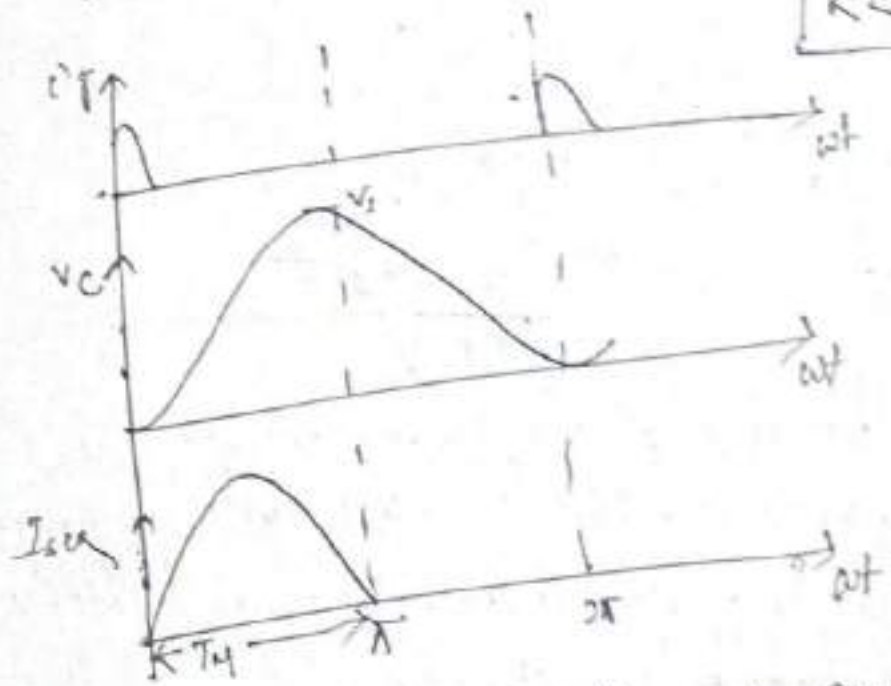
→ For high value of R , load R_L is connected across C .

→ The essential requirement for both the cut is that over all circuit must be underdamped.

When these cuts are energized from dc source current i first rises to maximum value and then begins to fall. When current decays to zero and tends to re-verse thyristor T is turned off on its own at instant t .

condition for underdamped

$$R < \frac{4L}{C}$$



The time for switching off the device is determined by the resonant frequency ω_r or ringing frequency which in turn depends on the value of the constituting components L & C and total circuit resistance.

for series RLC cut ringing frequency ω_r

$$\omega_r = \sqrt{\frac{1}{LC}} = \frac{R}{4L}$$

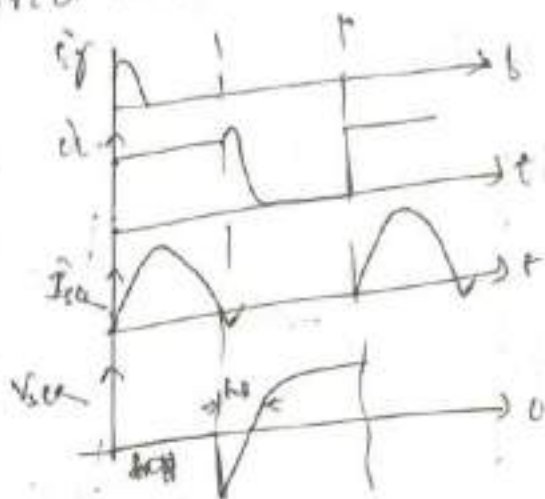
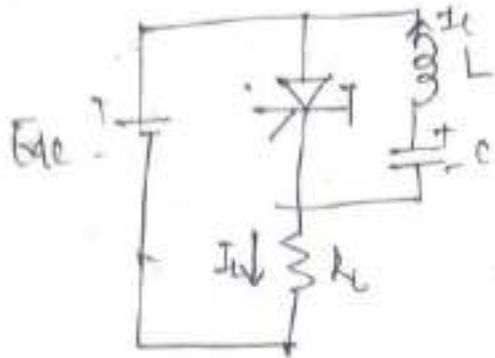
conducting time of thyristor $\omega_r t = \pi$
 $t = \frac{\pi}{\omega_r}$ sec

Applications

- This type of commutation circuits are most suitable for high frequency operations i.e. above 1000 Hz.
Exp used in series inverter.

CLASS-B or Resonant pulse commutator

- In this Method, the LC resonating circuit is across the SCR and not in series with the load.



- Initially as soon as the supply voltage E_{dc} is applied, the capacitor C starts getting charged with its upper plate +ve and the lower plate -ve & it charges upto voltage E_{dc} .
- When thyristor T is triggered, the circuit current flow in two directions.
- (1) The load current I_L flows through $E_{dc} - T - R_L - E_{dc}$
 - (2) Commutating current I_C
- The moment thyristor T is turned on, capacitor C starts discharging through the path $C - L - T - C$.

When the capacitor becomes completely discharged it starts getting charged with reverse polarity. Due to reverse polarity, a commutating current I_c starts flowing which opposes the load current.

When $I_c > I_L$, then thyristor is turned off. & capacitor C again starts getting charged with original polarity through L & load. Thus when it is fully charged thyristor will be on again.

Hence it is clear that the thyristor after getting on for sometime automatically gets off and after remaining in off state for sometime it again gets turned on.

design considerations

$$L \frac{di}{dt} + \frac{1}{C} \int i dt = 0$$

$$L \frac{dq}{dt} + \frac{1}{C} q = 0$$

Taking Laplace transform
 $(sL + \frac{1}{C}) I(s) = 0$

$$i(s) = E_0 e^{-\omega t} \sin \omega t$$

$$\text{where } \omega = \sqrt{\frac{1}{LC}}$$

Peak commutating current $I_{c(\text{peak})} = E_0 \sqrt{\frac{1}{LC}}$

$$T_{\text{off}} = \frac{1}{2} \sqrt{LC}$$

Voltage & current Rating of Thyristor

(21)

Assignment →

Protection of Thyristor

① Over current protection:

We must connect either fuses or CB in series with SCR for over current protection.

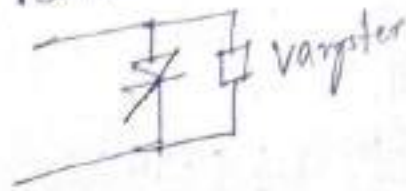
② Over voltage protection:

→ We must connect a varistor across the SCR for over voltage protection.

→ Varistor is a non-linear resistor.

→ All metal oxide resistor behave as non-linear resistor.

Exp 2-10



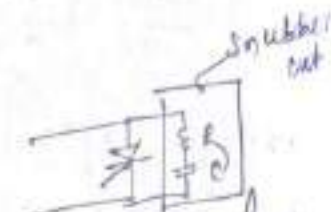
③ $\frac{dv}{dt}$ protection

$$I_C = C \frac{dv}{dt}$$

→ At very high $\frac{dv}{dt}$ SCR may turn on before the gate pulse is given. This is an unwanted turn on.

→ This unwanted turn on is also known as false turn on.

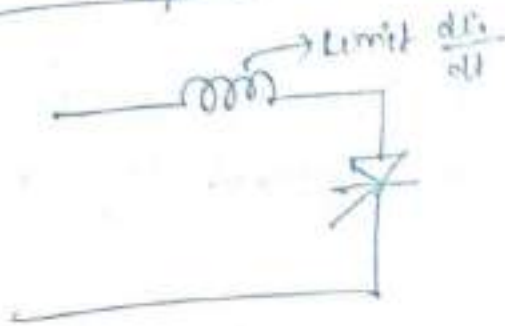
→ So we must connect a snubber circuit across the SCR for $\frac{dv}{dt}$ protection.



1) $\frac{di}{dt}$ Protection

We must connect an inductor in series when we are for $\frac{di}{dt}$ protection. Otherwise it will result in

Local hotspots hence damage the device.



2) Gate protection: (Ignoring I_g & I_{gmax})

→ overcurrent protection:

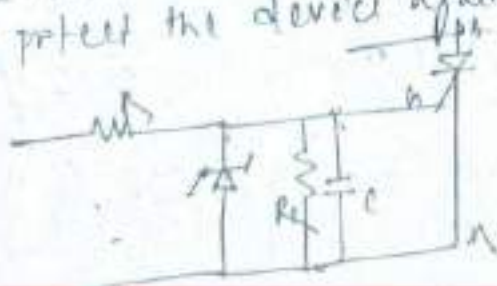
→ We must connect a resistor in series with the gate to limit the gate current with in the I_{gmax} value.

→ Over voltage protection

→ We must connect a zener diode across gate cathode terminals for over voltage protection in the gate.

Protection against noise signal

We must connect a parallel RC across gate cathode terminal to protect the device against noise signal.



Firing circuit of thyristor (23)

date: 14/05/19

As we know gate voltage control is the most common method for turning on the SCR.
The gate control circuit is also called firing or triggering circuit. These gating circuits are usually low power electronic circuit.

→ The basic requirements for successful firing of a thyristor are that the current supplied to the gate should

(A) be of adequate amplitude & sufficiently short rise time.

(B) be of adequate duration.

(C) occur at a time when the main circuit conditions are favourable to conduction.

Gate current amplitude:

→ The firing current I_{gmin} expresses the minimum gate current required to fire all thyristors of a given type at a standard temperature, however for satisfactory turn on & to reduce the turn on time, to increase di/dt rate & to reduce the turn on switching loss we normally require a firing current of about $1.4 I_{gmin}$.

Wave amplitude & rise time must be considered together in designing a firing circuit in accordance with any stipulated di/dt capability & switching performance.

For a successful firing we need high amplitude with a commensurately short rise time.

Gate pulse duration

Under favourable conditions, a thyristor may be triggered successfully by a gate pulse of duration approximately equal to turn on time of μs . However a considerably longer pulse duration is desirable for one or more of the following reasons:

(a) A relatively long period may be required for the anode current to rise to the latching current level.

(b) Oscillations, reflections or other disturbances may conspire to turn off the thyristor shortly after it is first triggered.

(c) There may be uncertainty as to whether the anode circuit conditions are favorable to conduction when the firing pulse is initiated.

- Two alternatives to use of a gate pulse long enough to cover the region of uncertainty of firing:
- (A) a control system in which the timing of the gate pulse is synchronized with the ~~gate~~ thyristor voltage or current zero rather than with supply voltage
 - (B) an extended train of short pulses



extended gate firing pulse with high initial amplitude

Gate Trigger circuit

- A firing circuit should fulfill the following two functions:
- (i) If the power circuit has more than one SCR the firing circuit should produce gating pulse for each SCR at the desired instant for proper operation of the power circuit
 - (ii) The control signal generated by a firing circuit may not be able to turn on an SCR. It is therefore common to feed the voltage pulses to a driver circuit and then to gate cathode circuit. The driver circuit consists of a pulse amplifier & pulse transformer

→ Resistance R should have ⁽²⁷⁾ such a value that Maximum voltage drop across it does not exceed Maximum possible gate voltage V_{GT} . This can happen only when $R_2 < R_1$ under this condition

$$\frac{V_m}{R_1 + R_2} \times R_2 \leq V_{GT}$$

$$\Rightarrow R \leq \frac{V_{GT} \times R_1}{V_m - V_{GT}}$$

→ As resistance R_1, R_2 are large, gate trigger ext. draws a small current. Diode 'D' allows the flow of current during positive half cycle only i.e. gate voltage V_G is half wave dc pulse. The amplitude of dc pulse can be controlled by varying R_2 .

→ The potentiometer setting R_2 determines the gate voltage amplitude. When R_2 is large, current I is small and the voltage across R_2 i.e. $V_G = I \times R_2$ is also small as shown in fig (1). As V_G (peak of gate voltage V_G) is less than V_{GT} (gate trigger voltage), SCR will not turn on. Therefore, load voltage V_o is 0 and supply voltage V_s appears only across SCR.

As trigger circuit consists of resistance only, V_G is therefore in phase with voltage V_s .

→ In 2nd fig V_G is adjusted such that $V_G > V_{GT}$ which gives the value of firing angle α .

→ In 3rd fig. $V_G > V_{GT}$. As soon as V_G becomes equal to V_{GT} for the first time SCR is turned on. As resistance triggering can't give firing angle beyond 90° .

→ A relationship between V_{gp} & V_{gt} can be expressed as follows

$$V_{gp} \sin \alpha = V_{gt}$$

$$\Rightarrow \alpha = \sin^{-1} \left[\frac{V_{gt}}{V_{gp}} \right]$$

Since $V_{gp} = \frac{V_m R}{R_1 + R_2 + R}$

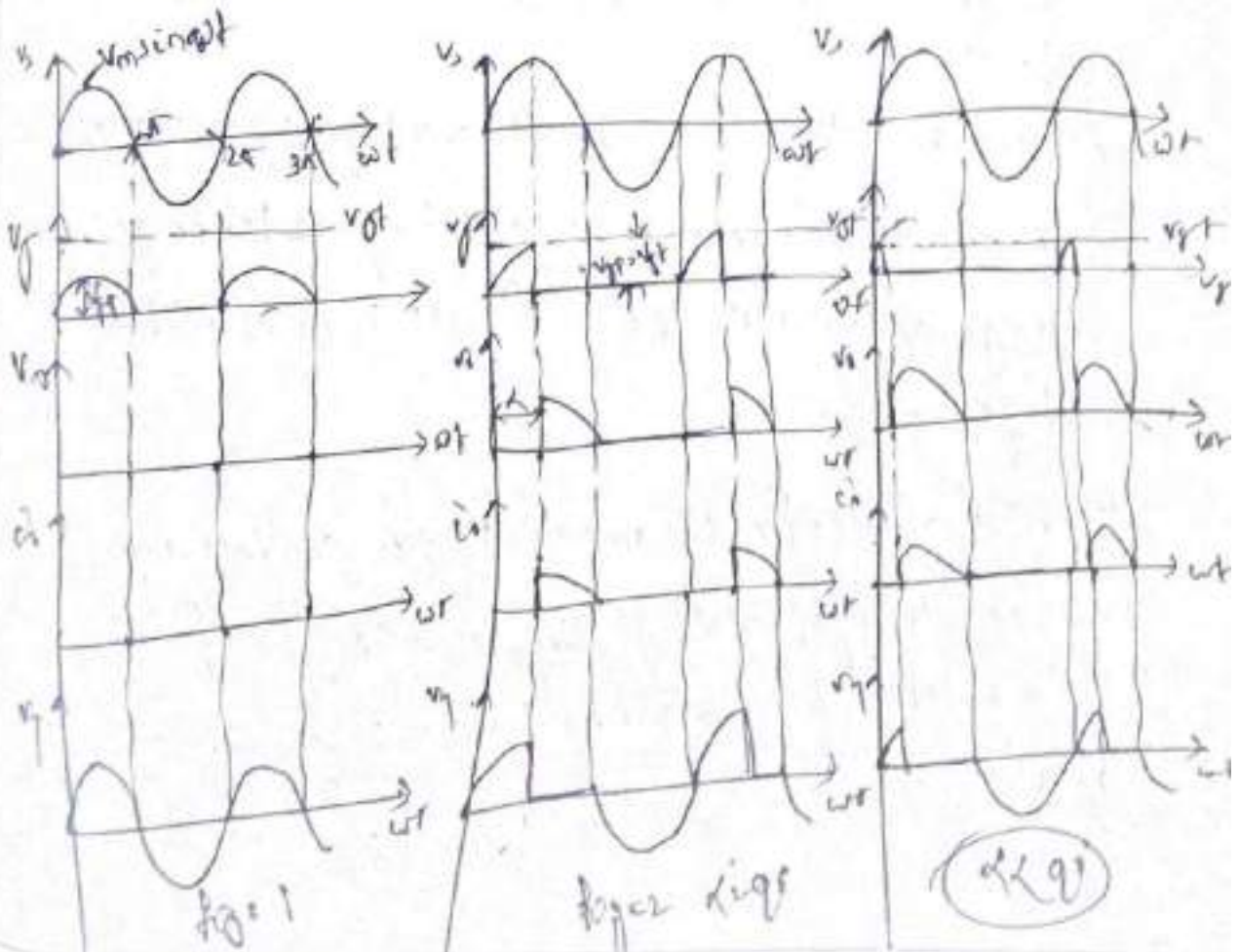
$$\Rightarrow \alpha = \sin^{-1} \left[\frac{V_{gt} (R_1 + R_2 + R)}{V_m R} \right]$$

As V_{gt} , R_1 , R_2 & V_m are fixed.

$$\Rightarrow \alpha \propto \sin^{-1}(R_2)$$

$$\text{or } \boxed{K \alpha \approx R_2}$$

→ As the firing angle control is from 0° to 90° the half wave power o/p can be controlled from 100% (at 0°) down to 50% (at 90°)



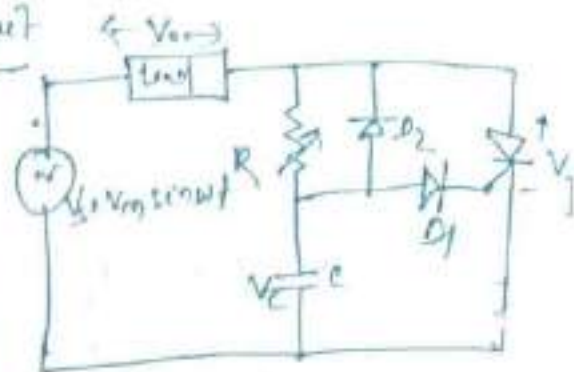
RC firing circuit

(29)

DATE: 17/08/19

(1) half wave trigger circuit

By varying the value of R , firing angle can be controlled from $0-180^\circ$



→ on the -ve half cycle, capacitor C charges through D_2 with lower plate +ve to the peak supply V_m at $\omega t = -90^\circ$.

→ after $\omega t = -90^\circ$, source voltage V_s decreases from $-V_m$ at -90° to zero at $\omega t = 0^\circ$. During this period, capacitor voltage V_c may fall from $-V_m$ at $\omega t = -90^\circ$ to some lower value $-0a$ at $\omega t = 0^\circ$.

→ now as the SCR anode voltage passes through zero and becomes +ve, C begins to charge through variable resistance R from initial voltage $-0a$.

→ When capacitor charges to +ve voltage equal to gate trigger voltage V_{gt} , SCR is fired and after this capacitor holds a small +ve voltage.

→ etc

$$V_s \gg R I_{gt} + U_c$$

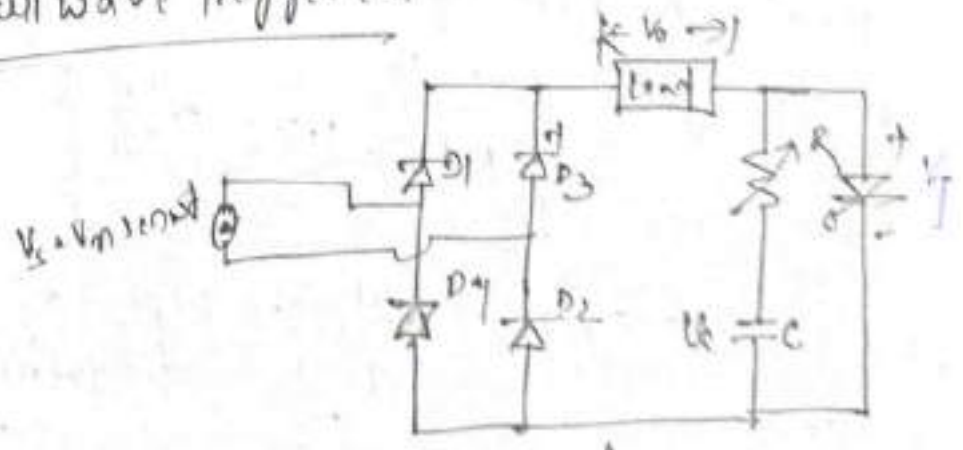
$$U_s \gg R I_{gt} + U_{gt} + V_d$$

$$R \leq \frac{U_s - U_{gt} - U_d}{I_{gt}}$$

where U_s = source voltage at which thyristor turn on.

→ on the above figure if R is more the time taken for c to charge from $-0a$ to $(U_{gt} + V_d)$ is more, firing angle is more and therefore average o/p voltage is low. if R is less, firing angle is low and therefore average o/p voltage is more.

(1) RC full wave trigger cut



→ on this case initial voltage from which the capacitor 'c' charges is almost zero.

→ The value of RC is calculated by empirical formula

$$RC \gg 50 \frac{1}{\omega} \approx \frac{157}{\omega}$$

$$R \ll \frac{V_s - V_{gt}}{I_{gt}}$$

Unijunction Transistor

(32)

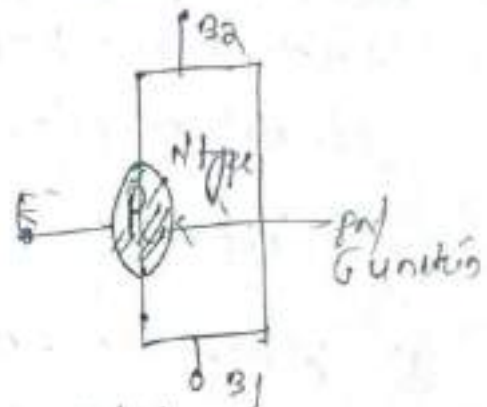
DATE: 19/05/19

- The unijunction transistor is a three-terminal single junction device.
- UJT is always operated as a switch and finds most frequent applications in oscillator, timing circuits & SCR/Triac trigger circuits.

Basic operation

→ An UJT is made up of an n-type silicon base to which p-type emitter is embedded closer to B_2 .

→ The n-type base is lightly doped where as p-type is heavily doped.



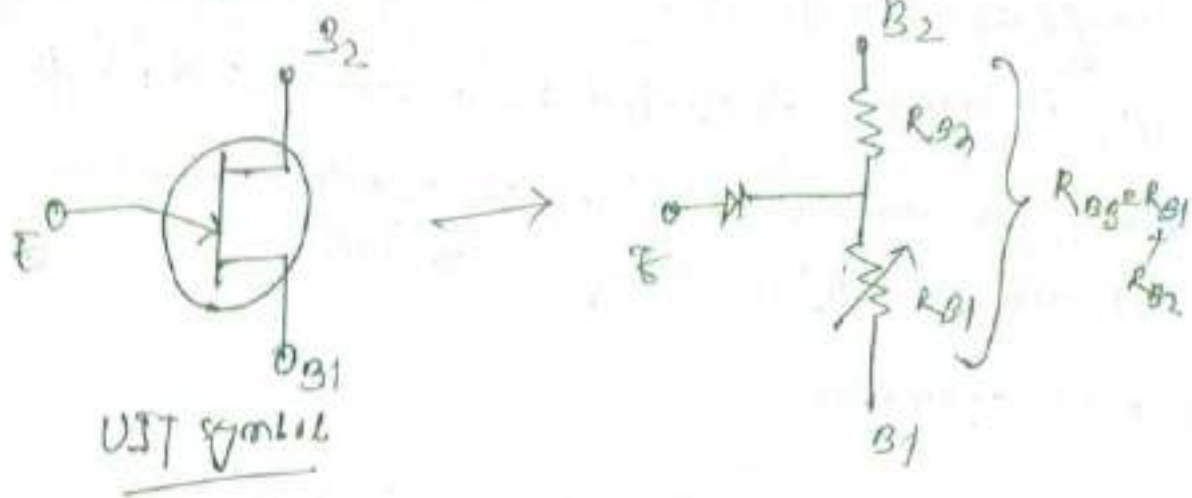
→ The two ohmic contact provided at each end are called base one (B_1) & base two (B_2). So unijunction transistor has 3 terminals namely Emitter (E), Base one (B_1) & Base two (B_2).

→ Between B_1 & B_2 an interbase resistance is present (R_{BB})

→ This interbase resistance is broken into two resistances (i) the resistance from B_1 to E $\rightarrow R_{B1}$
(ii) the resistance from B_2 to E $\rightarrow R_{B2}$.

→ Since emitter is closed to B_2 so $R_{B1} > R_{B2}$.

VJT symbol & equivalent circuit



→ The diode represents the p-n junction b/w emitter & base bar. & R_{B1} is variable during normal operation.

VJT operation

- (1) When the emitter diode is reverse biased only a very small emitter current flows. Under this condition R_{B1} is at normal high value. This is the off state.
- (2) When the emitter diode becomes forward biased, R_{B1} drops to a very low value so that the total resistance b/w E & B1 is very low, allowing emitter current to flow readily. This is the on state.

Unijunction Transistor (92)

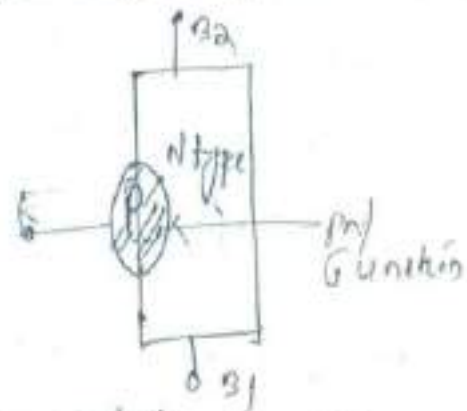
DATE: 19/05/19

- The unijunction transistor is a three-terminal single junction device.
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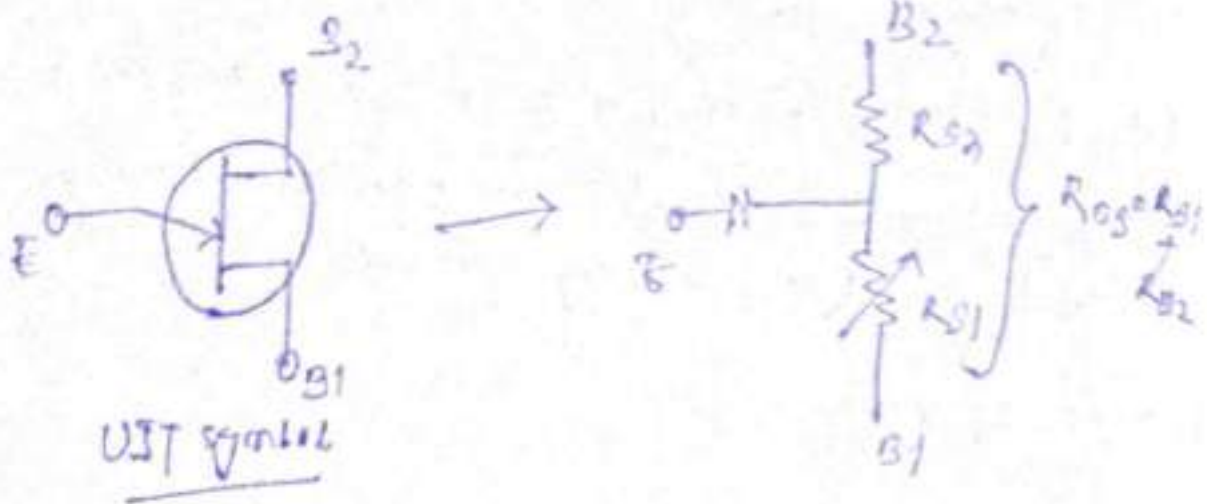
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Between B_1 & B_2 an interbase resistance is present (R_{BB})

This interbase resistance is broken into two resistances (i) the resistance from B_1 to E $\rightarrow R_{B1}$
(ii) the resistance from B_2 to E $\rightarrow R_{B2}$.

→ Since emitter is closest to B_2 so $R_{S1} > R_{S2}$.

VDT Symbol & equivalent circuit



→ The diode represents the pn junction b/w emitter & base bar. & R_{S1} is variable during normal operation.

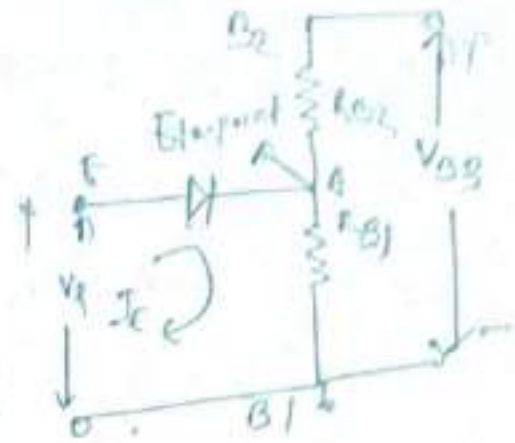
VDT Operation

- (1) When the emitter diode is reverse biased only a very small emitter current flows. Under this condition R_{S1} is at normal high value. This is the off state.
- (2) When the emitter diode becomes forward biased, R_{S1} drops to a very low value so that the total resistance b/w E & B1 is very low, allowing emitter current to flow readily. This is the on state.

inverted operation

(34)

When voltage V_{B2} is applied across the two base terminal the potential of point A with respect to B_1 is given by -



$$V_{AB} = V_{B2} \times \frac{R_{B1}}{R_{B1} + R_{B2}}$$

$$V_{AB} = \eta V_{B2}$$

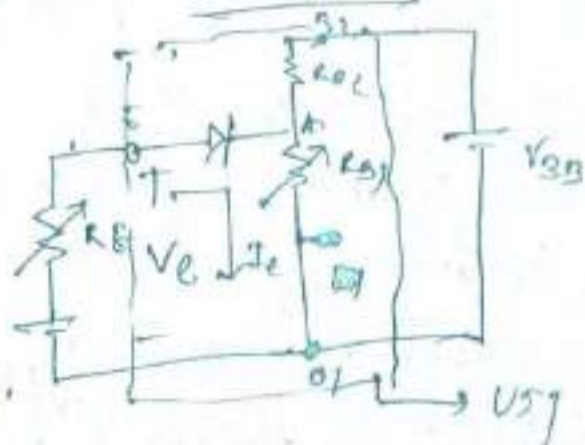
where $\eta = \frac{R_{B1}}{R_{B1} + R_{B2}}$ is called intrinsic standoff ratio.

$$0.5 < \eta < 0.9$$

The interbase resistance $R_{BB} = R_{B1} + R_{B2}$ is of the order (5-10 k Ω).

Since E is closer to $B_2 \Rightarrow R_{B2} < R_{B1}$

→ The magnitude of V_e can be varied by regulating external resistance R_e .



→ Using as $V_e < \eta V_{B2}$, the E-B₁ is reverse biased & the emitter current is -ve as shown by the curve p.s. The region p.s. of very low current is treated as off switch.

→ R_{B1} is very high

→ The resistance between E-B₁ Junction is therefore very high.

→ At S; $I_e = 0$, drop across $R_B = 0$ therefore $V_e = \text{source voltage i.e. } 0 \text{ so } V_e = V_{EE}$

→ So when $V_e = 2V_{BE} + V_0$, point ^B is reached and E-B₁ Junction gets forward biased to allow forward current through the diode

→ point B is called peak point and at this point voltage is V_p & current is I_p which is known as peak point voltage & peak point current respectively.

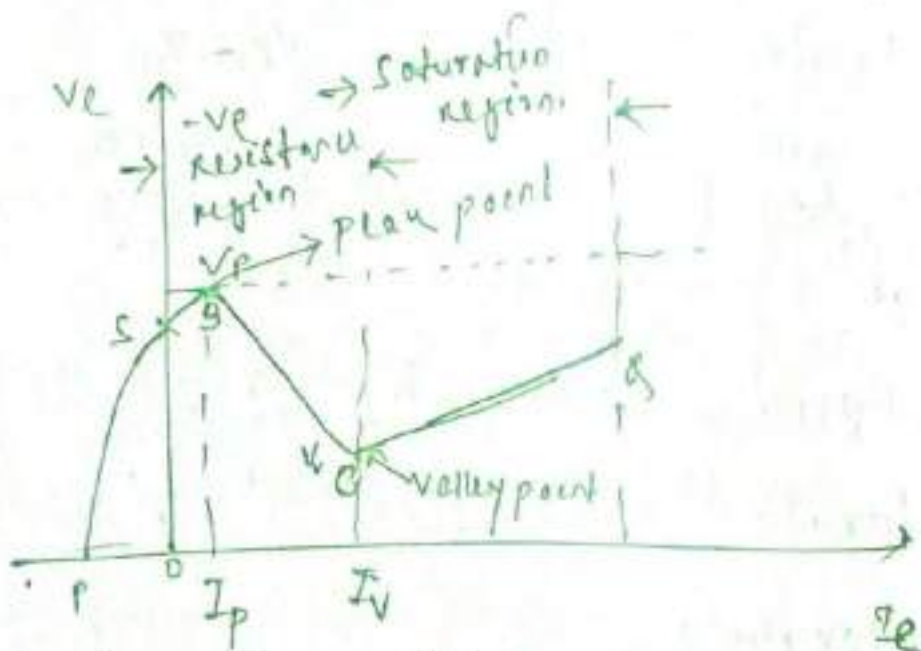
→ By varying R_B , V_e is increased till V_e approaches V_p . At this peak point $V_e = 2V_{BE} + V_0$ the p-emitter begins to inject holes from the heavily doped emitter E into the lower base region B₁. As n-type Base is lightly doped the holes rarely get any chance to recombine.

→ The lower base B₁ is therefore filled up with additional current carriers (holes). As a result resistance R_{B1} of E-B₁ Junction decreases.

- The fall in R_{B1} causes ⁽³⁶⁾ potential of point A to drop
- This drop in V_A in turn causes $V_E = V_A + V_D$ to fall. As V_{EE} is constant, fall in V_E gives rise to more emitter current $I_E = \frac{V_{EE} - V_E}{R_E}$.
- This increased I_E injects more holes into region B₁, thereby further reducing the resistance R_{B1} and soon. This effect known as regenerative or snow-balling effect which continues till R_{B1} has dropped to a small value (at base).
- The emitter current limited by external resistance R_E is then given by $I_E = \frac{V_{EE} - V_D}{R_{B1} + R_E}$
- When R_{B1} has dropped to a very small value indicated by point 'c'.
- At point 'c' entire base region B₁ is saturated and resistance R_{B1} can't decrease further more.
- The point 'c' is called the valley point & V_V & I_V are the corresponding valley voltage & valley current.
- After that is on or after valley point is reached an increase in V_E is accompanied by increase in

I_e ; this is indicated by curve CA. (37)

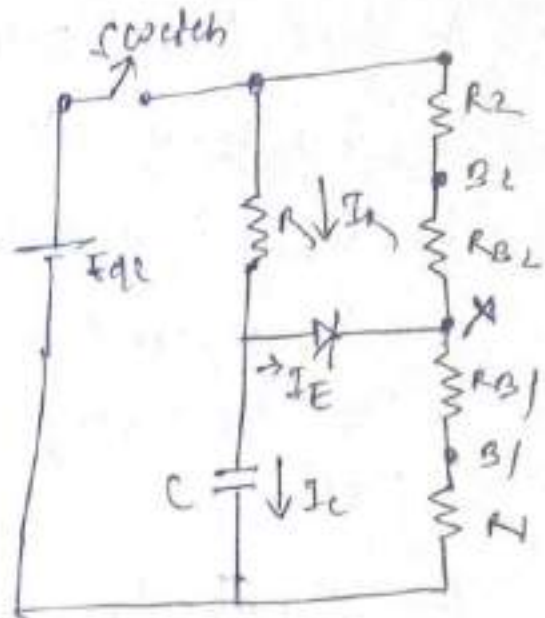
- At point B, v_e is little more than its valley point voltage v_v .
- Between B & C, emitter voltage v_e falls as I_e increases; UJT therefore exhibits negative resistance between these two points.
- At the valley point, the current is given by V_p / R_{B1} . Valley point current, also called holding current, keeps UJT on. When I_e falls below I_V UJT is off.



UJT relaxation oscillator

The most common UJT circuit in use today is the relaxation oscillator which is shown in the figure. Also this type of circuit is basic to other timer or trigger circuit.

Let us consider a situation in which capacitor is at zero volt. The switch is suddenly closed at $t=0$, applying E_{dc} to the circuit. Since $V_B = V_C = 0$, the VJT emitter diode is reverse biased and VJT is off.



$$V_x = E_{dc} \times \frac{(R_{B1} + R_1)}{R_{B1} + R_{B2} + R_1 + R_2}$$

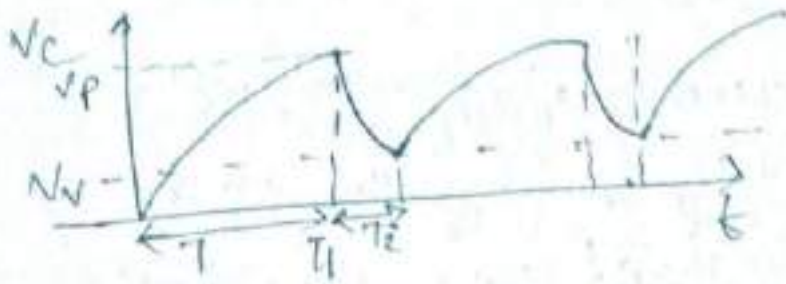
Normally R_1, R_2 is much smaller than R_{B1}, R_{B2} so $V_x \approx E_{dc}$.

→ In this condition the only emitter current flowing will be small reverse leakage I_{E0} . So emitter is open. Now capacitor will begin to charge towards the input voltage E_{dc} through R_1 .

→ The capacitor voltage increases with a time constant of RC . It will continue to increase till voltage of emitter reaches to peak point voltage V_p .

- At this time, emitter diode becomes forward biased and V_{BE} turns on with I_{B1} dropping to very low value. Since the diode is now forward biased, the capacitor will discharge through load resistor path containing the diode, R_B , & r_{E1} .
- The capacitor discharge time is necessary and compared to its charging time.
- The discharging capacitor provides the emitter current needed to keep the V_{BE} 'on'; it will remain on until I_E drops below the valley current I_V at which time the V_{BE} will turn off. This occurs at time T_2 when the capacitor voltage drops to valley voltage V_V . At this time, I_{B1} returns to its off value, the diode is again reverse biased & $I_{B1} = 0$.
- The capacitor will begin charging towards V_{CC} once again and the previous chain of events will repeat itself indefinitely so long as power is applied to the circuit. The result is a periodic sawtooth wave form.

(40)



The length of one period of \$T_1\$ is essentially the time it takes for the capacitor to charge to \$V_p\$ since the discharging time \$T_2\$ is usually very short. Thus \$T \approx T_1\$

$$T_2 \approx RC \ln \left[\frac{E_{dc}}{E_{dc} - V_p} \right]$$

on most cases $\frac{V_p}{E_{dc}} \approx \frac{2 E_{dc} + V_0}{E_{dc}}$

$$T \approx RC \ln \left[\frac{2 E_{dc}}{E_{dc} - (2 E_{dc} + V_0)} \right]$$

$$T \approx RC \ln \left[\frac{2 E_{dc}}{E_{dc} (1 - 2) + V_0} \right]$$

normally \$V_0 \approx 0\$

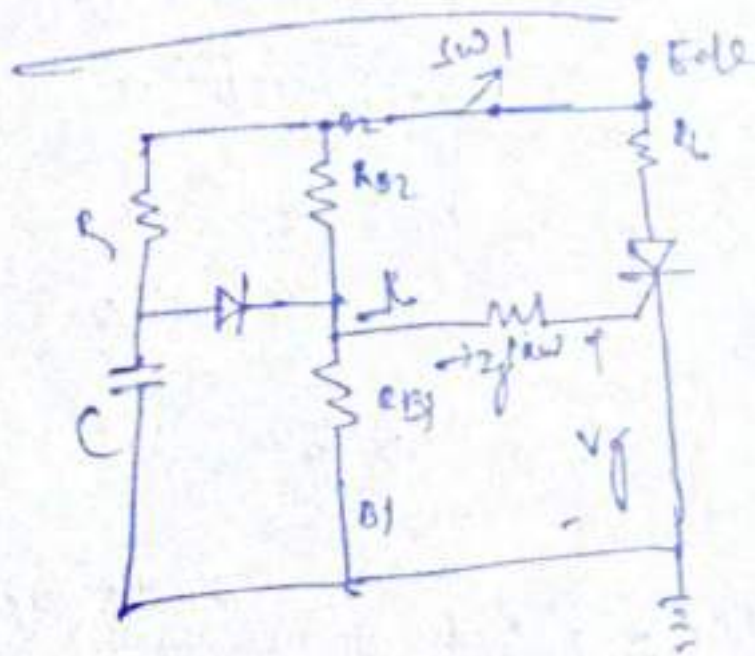
$$\Rightarrow T \approx RC \ln \left[\frac{2 E_{dc}}{(1 - 2) E_{dc}} \right]$$

$$\boxed{T \approx RC \ln \left(\frac{2}{1 - 2} \right)}$$

→ The frequency of oscillation can be controlled by varying the charging time constant RC . Then the limits on R are

$R_{min} \geq$	$\frac{E_{dc} - V_0}{I_V}$
$R_{max} \leq$	$\frac{E_{dc} - V_f}{I_p}$

THE UJT as an SCR trigger



(12)

Pulse transformer in triggering circuits

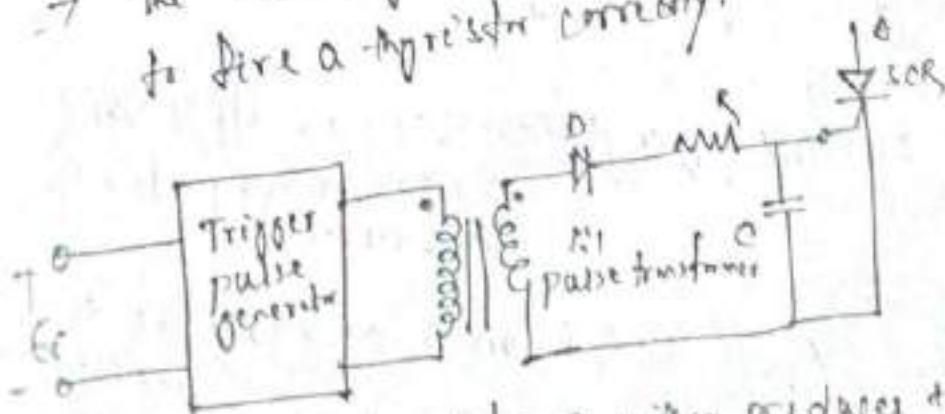
DATE: 2/05/19

- pulse transformers are used quite often in firing circuits for SCRs and GTOs. These transformers have usually two secondaries. The turn ratio from primary to secondaries is 2:1:1 or 1:1:1.
- These transformers are designed to have low winding resistance, low leakage reactance & low interwinding capacitance.

Advantage of using pulse transformer in triggering circuit

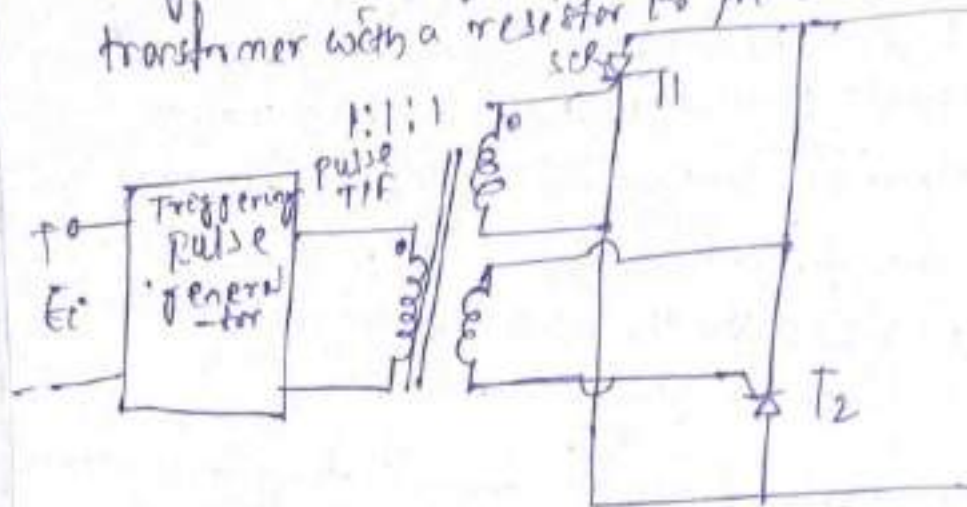
- (i) The isolation of low voltage gate circuit from high voltage anode circuit.
- (ii) The triggering of two or more devices from the same trigger source.

→ The below figure shows a complete output circuit to fire a thyristor correctly.



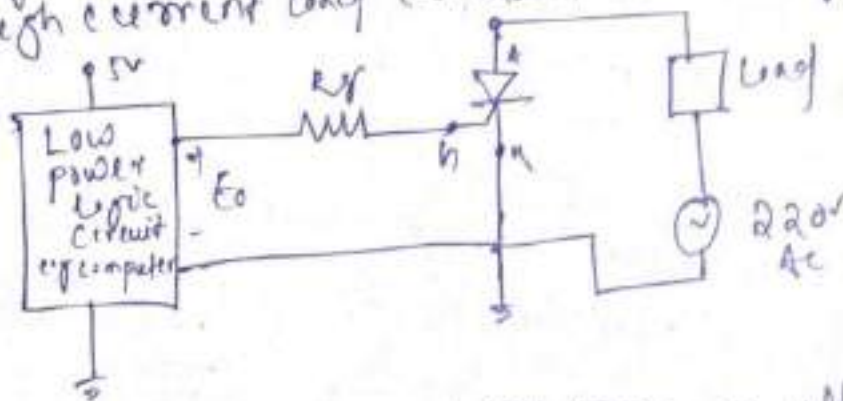
- The series resistor 'R' either reduces the SCR holding current or balances the gate current in a 3-winding transformer connected to two SCRs.
- The series diode 'D' prevents reverse gate current in case of reversal of the pulse transformer output voltage.

→ In some cases where high noise level is present it may be necessary to load the secondary of the transformer with a resistor to prevent false triggering.



Optical isolator (optoisolator)

→ A common situation where a low voltage, low current logic circuit controlling a high voltage and high current load is shown in below fig.



When $E_o = 0V$ (ground) \Rightarrow SCR is off & the load receives no power from the source.

When $E_o = 5V \Rightarrow$ SCR is on & the 230V ac is switched on.

→ Generally it is not desirable to have a direct electrical connection between low power control circuit and the high-power load it controls, as done in the circuit.

Disadvantage of relay

→ Needs being coupled from high current circuit to low power logic circuit
(especially over long lines)

→ There is a possibility of high voltage from the load circuitry feeding back into the logic circuit as a result of component failure

→ Another means for solving this is to use an electromechanical relay.

→ In this case the logic circuit drives the low current relay coil and the relay magnetically controls the switch contacts that connect power to load

disadvantages of electromechanical relay

→ They are fairly expensive

→ Relays are bulkier than solid state devices

→ They create magnetic fields and inductive kick which can be troublesome sources of electrical noise

→ Relays have shorter life than semiconductor devices

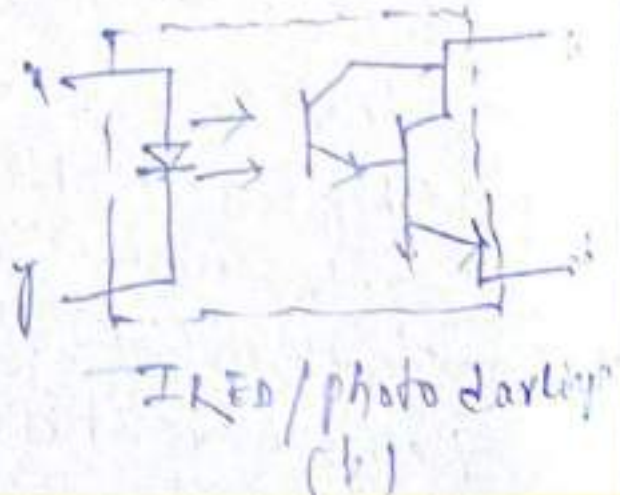
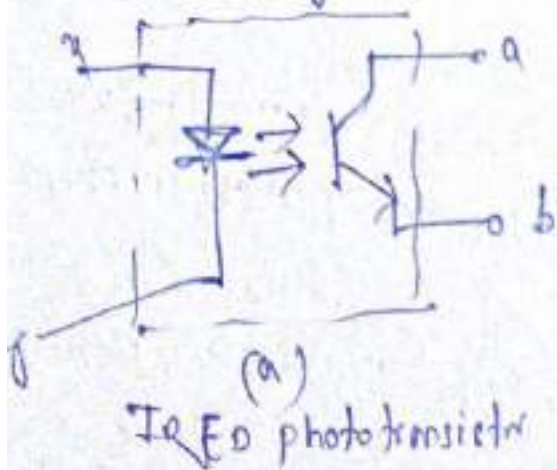
→ The contacts create sparking upon opening

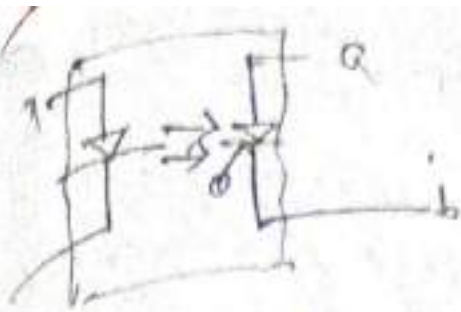
→ These above disadvantages can be overcome by the device called optical isolator, when the light energy transmits the control signal to the load.

→ Optical isolator consists of a light source (usually an infrared emitting diode) a light sensitive device (or) photo transistor and a switching device.

→ The input circuit is usually an IREDA which emits IR radiation when it is sufficiently forward biased. This radiation is focused on a light sensitive device such as switches or photo transistor. Sufficient current flows through IREDA.

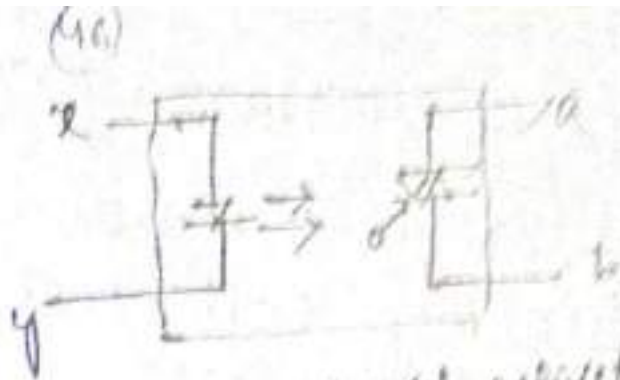
→ The optical isolator in fig (a), (b), & (c) we use to switch dc power to a load while the in fig (d) & (e) can switch ac power.



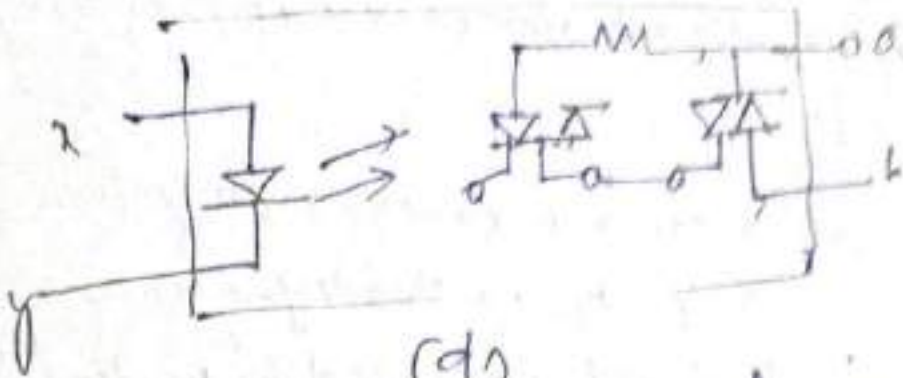


IR LED/LASER

(c)



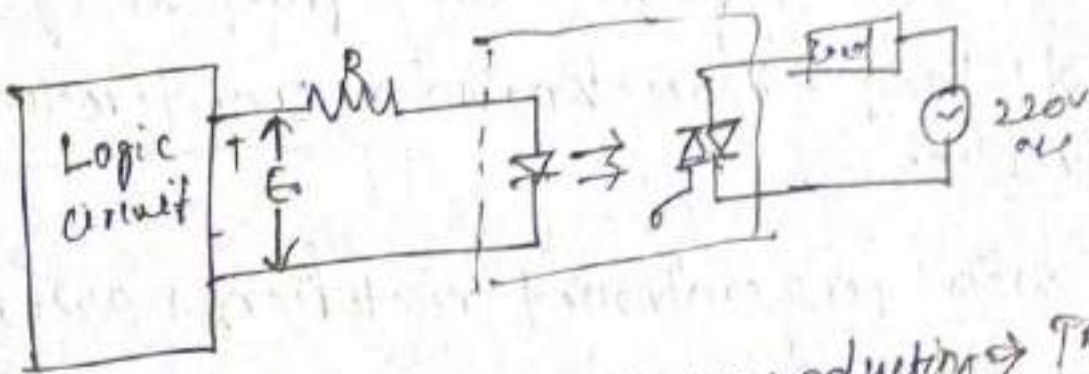
(d) IR LED/Light emitting diode



(e)

IR LED / Triac / Triac for high current ac

Electrical isolation provided by an optoisolator



When $E = 0V$ IR LED is non-conducting \Rightarrow TRIAC is off
 So load receives no ac voltage

When $E = 5V$ IR LED conducts \Rightarrow TRIAC = on
 So load receives ac voltage

Introduction Phase Controlled Converter ⁽¹⁷⁾ Defination/orig

- Rectification is a process of converting an alternating current (or) voltage into a direct current & voltage.
- This conversion can be done using switch devices like Diode, thyristor, power transistor, power mos etc.

Rectifier →

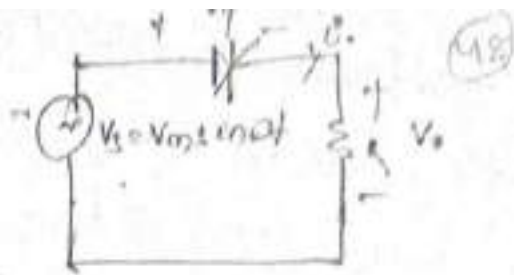
- uncontrolled → using diode
- fully controlled → using thyristor
- half controlled → Diode & thyristor

↓
half controlled rectifier is cheaper than fully controlled rectifier.

- Uncontrolled & half controlled rectifiers will permit power to flow only from ac system to dc load & hence known as unidirectional converter.
- But with fully controlled rectifier, power can be transferred from dc side to ac system also. This is why it is known as bidirectional converter.

Control Techniques (Phase Control)

- The simplest form of rectifier circuit consist of a single thyristor feeding dc power to a resistive load R .



An SCR can conduct only when anode voltage is +ve and a gating signal is applied. Thyristor blocks the flow of load current 'i_o' until it is triggered.

→ Suppose at some firing delay angle α , a +ve gate signal is applied between gate & cathode which turns on the SCR. Immediately full supply voltage is applied to load as V_s .

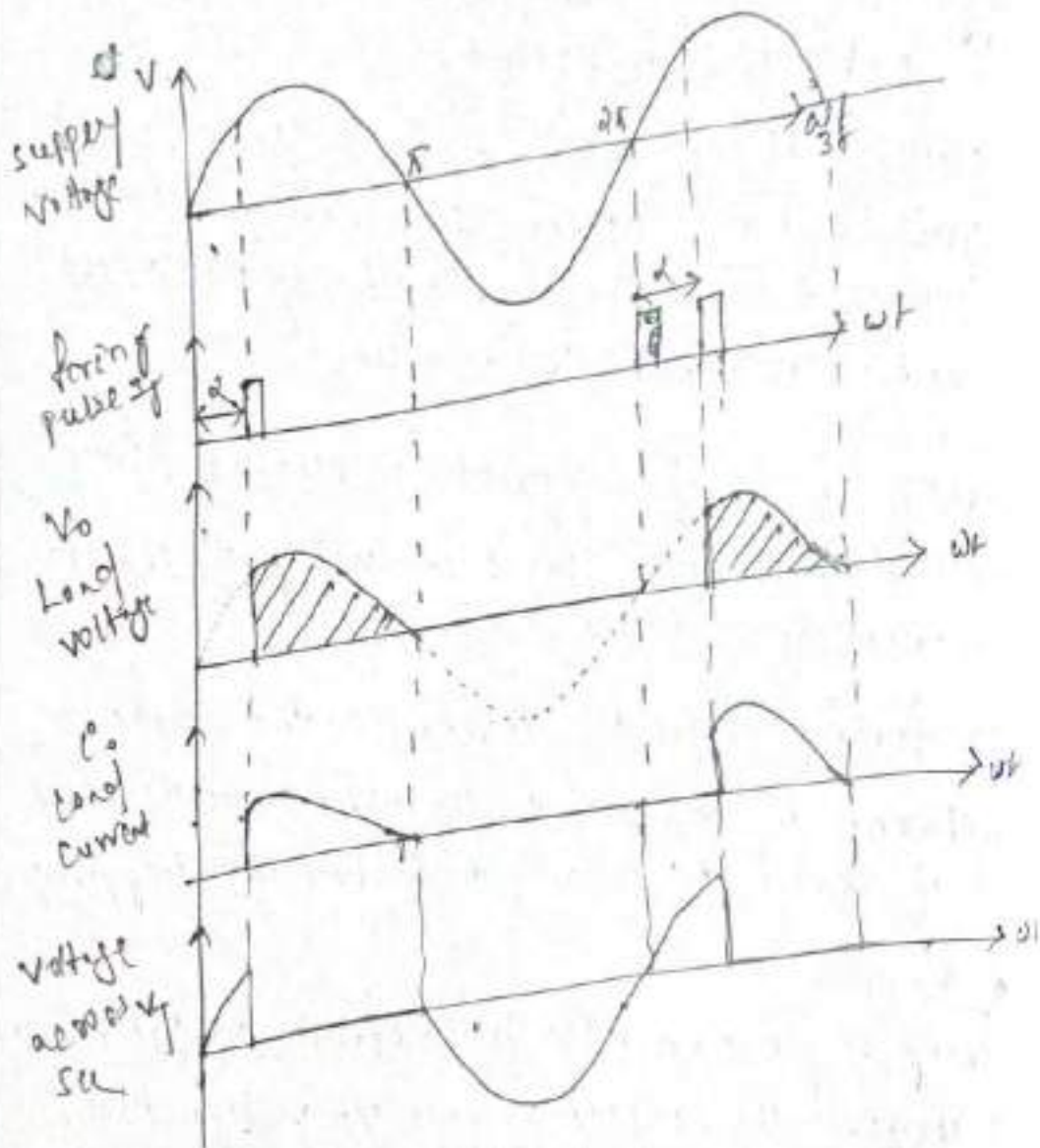
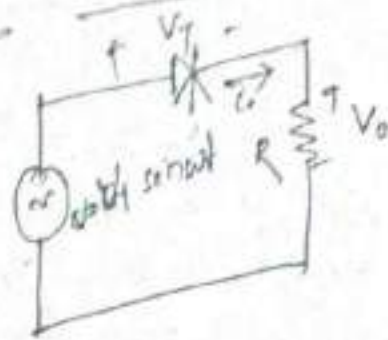
→ firing angle of a thyristor is measured from the instant it would start conducting, if it were replaced by a diode.

→ so firing angle is defined as the angle between the instant the thyristor would conduct if it were a diode and the instant it is triggered.

OR
firing angle can also be defined as the instant that gives the largest average o/p voltage to the instant it is triggered.

if
firing angle also defined as the angle measured from the instant SCR gets forward biased to the instant it is triggered.

① Single phase half wave controlled Rectifier with R-load



Average output voltage:

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

$$= \frac{V_m}{2\pi} [-\cos \omega t]_{\alpha}^{\pi} = \frac{V_m}{2\pi} (-[0 - 1 - \cos \alpha])$$

$$V_o = \frac{V_m}{\pi} (1 + \cos \alpha) \quad (2)$$

$$V_o |_{\text{Max } \alpha=0} = \frac{V_m}{\pi}$$

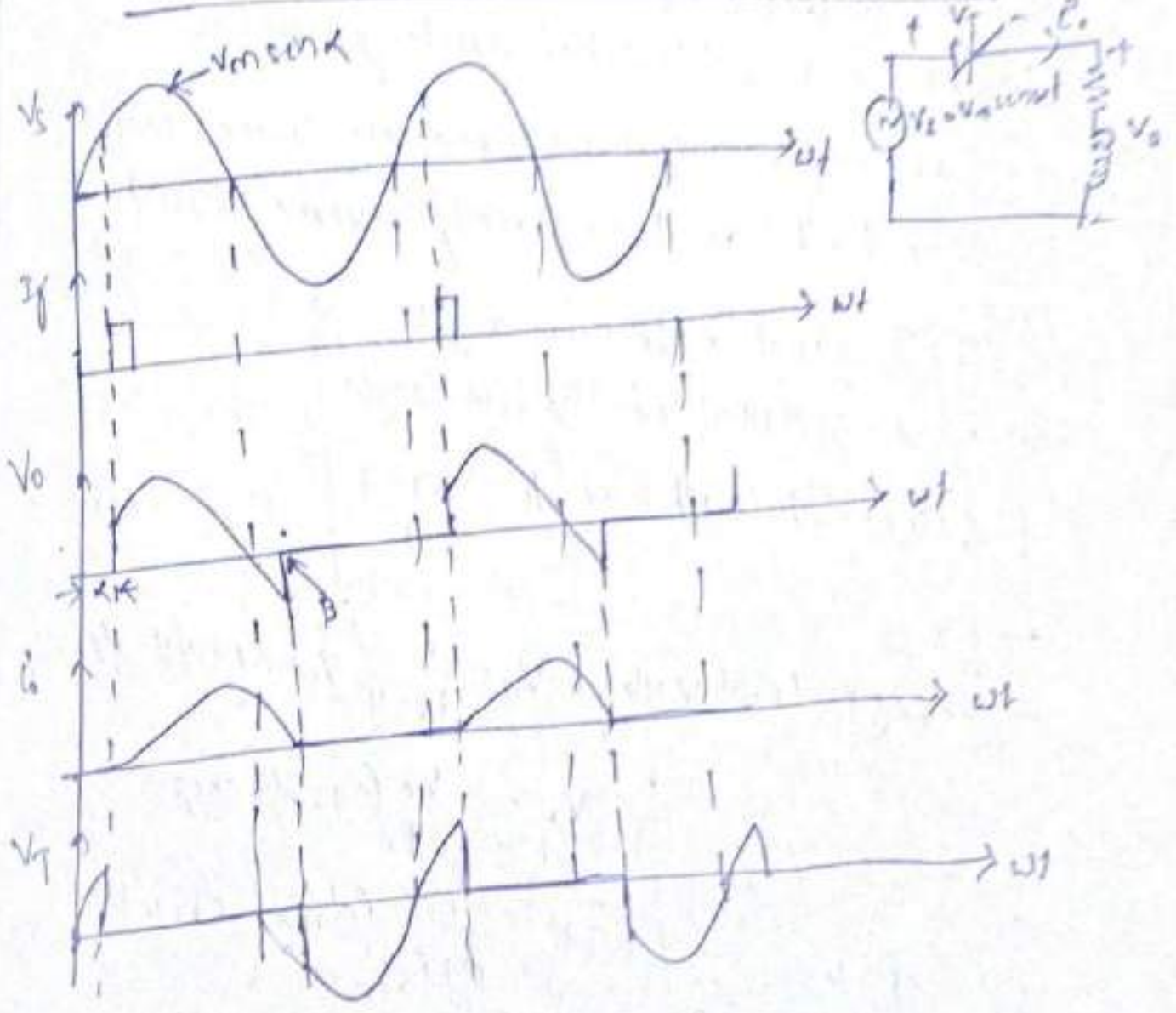
$$\text{Conduction angle} \\ \gamma = \pi - \alpha$$

Average Load Current

$$\omega L < R \\ \gamma = \pi - \alpha$$

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

3) Single phase half wave controlled rectifier with RL Load



- (51)
- At $\omega t = \alpha$, thyristor is turned on by gating signal. The load voltage V_o at once becomes equal to source voltage V_s . But the inductor L forces the load or output current i_o to rise gradually. After some time i_o reaches maximum value and then begins to decrease.
- At $\omega t = \pi$, V_o is zero but i_o is not zero because of conduction L .
- After $\omega t > \pi$, S_1 is subjected to reverse anode voltage but it will not be turned off as load current i_o is not less than holding current.
- At some angle $\beta > \pi$, i_o reduces to zero and S_1 is turned off as it is already reverse biased.

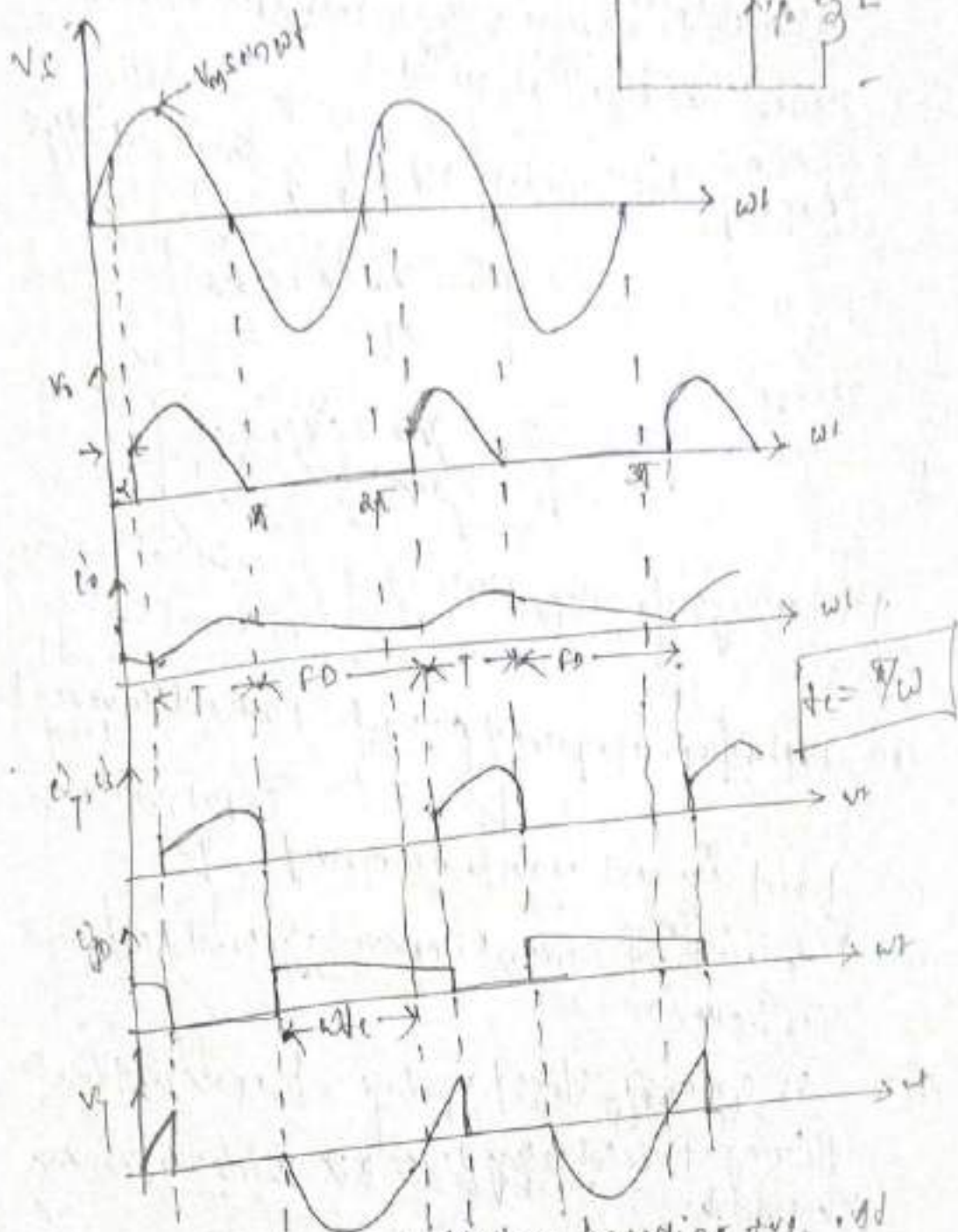
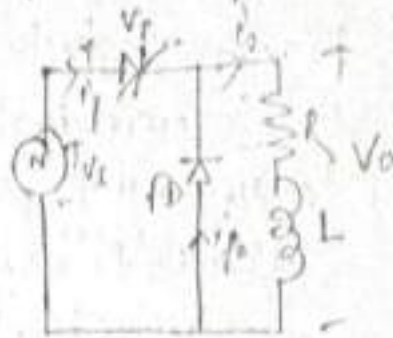
β is called extinction angle
 $\beta - \alpha = \gamma$ called conduction angle
 Circuit turn off time $t_c = \frac{\alpha\pi - \beta}{\omega}$

Average load voltage $V_o = \frac{1}{2\pi} \int_{\alpha}^{\beta} V_m \sin \omega t \, d\omega t$

$V_o = \frac{V_m}{2\pi} (\cos \alpha - \cos \beta)$
 $I_o = \frac{V_m}{2\pi R} (\cos \alpha - \cos \beta)$

Single phase half wave circuit with R_L load & FD. DATE: 22/11/17

Also called bypass or commutating diode
 FD \rightarrow freewheeling diode



At $\omega t = 0$, source voltage becoming +ve. At some delay angle α , forward biased sc is triggered and source voltage V_s appeared across load as V_o .

→ At $t = t_1$, source voltage is V_s and
 but after that source is disconnected and
 free wheeling diode conduction frequency
 range is ω . As a result of current
 is i_L and it is i_L and it is i_L and it is i_L
 or i_L and it is i_L and it is i_L and it is i_L
 subject to reverse voltage and it is i_L and it is i_L
 from $t = t_1$ to $t = t_2$

Average load voltage $V_o = \frac{1}{\Delta t} \int V_o \text{ and } dt$

$$V_o = \frac{V_s}{\Delta t} \text{ (1/2)} \text{ and } dt$$

$$I_o = \frac{V_o}{R} \text{ (1/2)} \text{ and } dt$$

Advantage of using FDI

- (i) PF is improved \because $\frac{\text{Power delivered}}{\text{Input}} \text{ will improve}$
- (ii) Load current waveform improved
- (iii) since load current improved \Rightarrow load performance is better
- (iv) as energy stored in L is transferred to load during free wheeling period \Rightarrow overall efficiency improves.

Disadvantage of half wave converter

From half wave converter, the supply current is taken for ω and is unidirectional and is in the form of dt pulse.

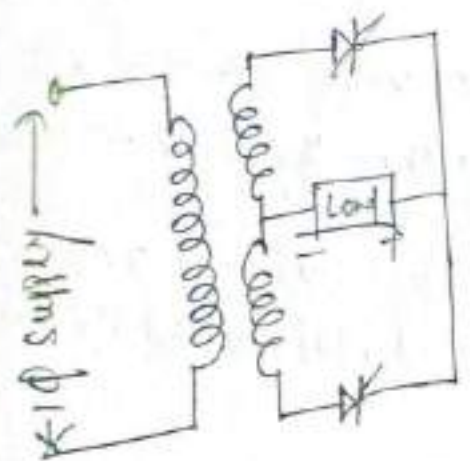
→ Single phase half wave converter thus introduces a dc component into the supply line. This is undesirable as it leads to saturation of the supply transformer and other difficulties (harmonics etc)

→ These shortcomings can be overcome by to some extent by use of single phase full wave circuits

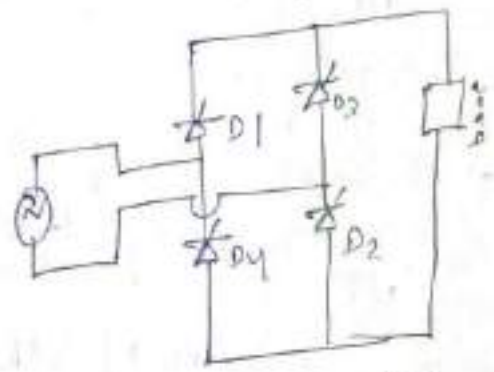
Single phase full wave converter:

(i) Mid point converter

(ii) Bridge converter

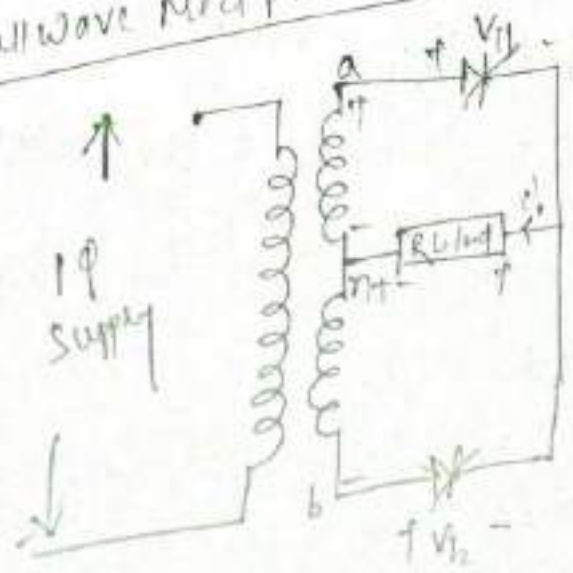


(i) Mid point connection



Bridge converter

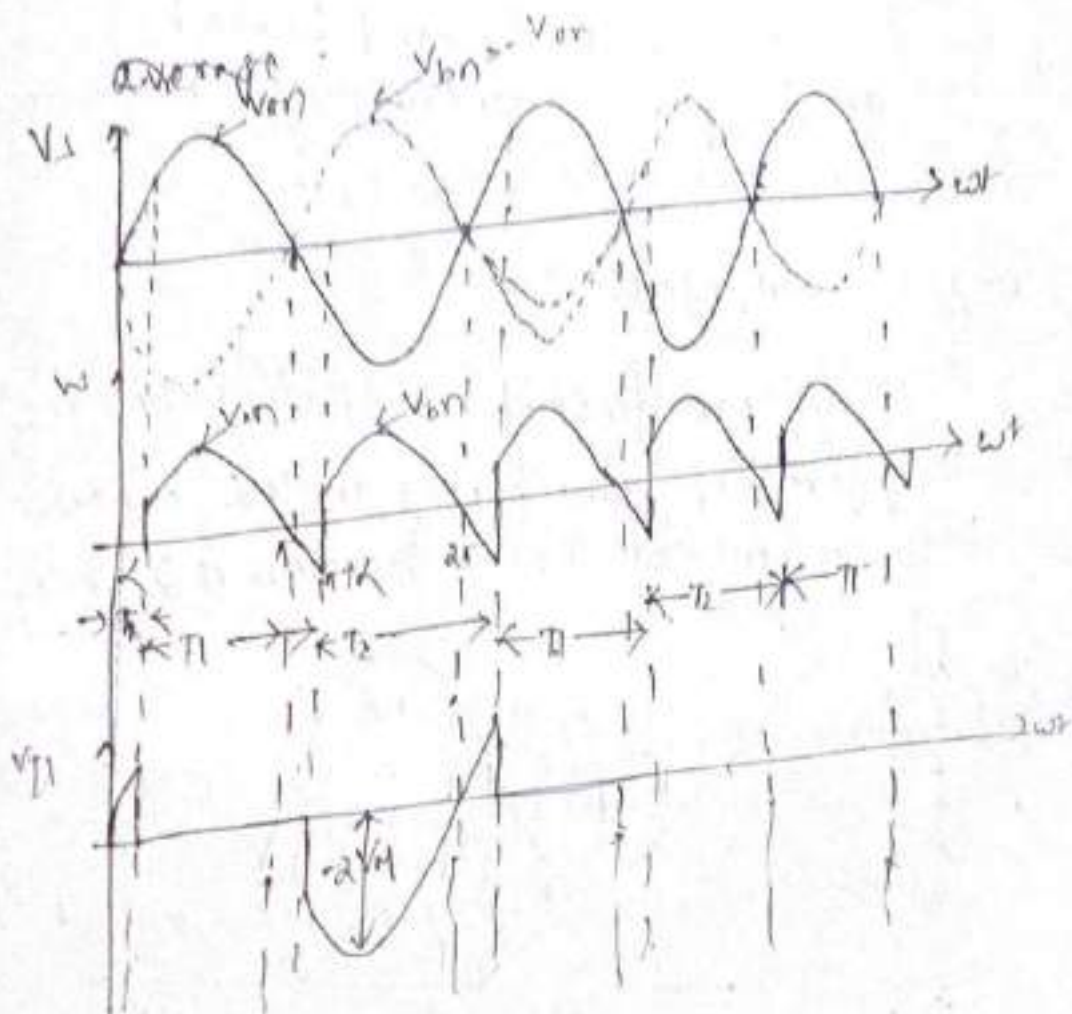
Single phase full wave Mid point converter (Circuit connection)



At $\omega t = \pi + \alpha$, T_2 is triggered, T_1 is reverse biased by voltage of magnitude $2V_m \sin \alpha$ & current is transferred from T_1 to T_2 , T_1 is therefore turned off.

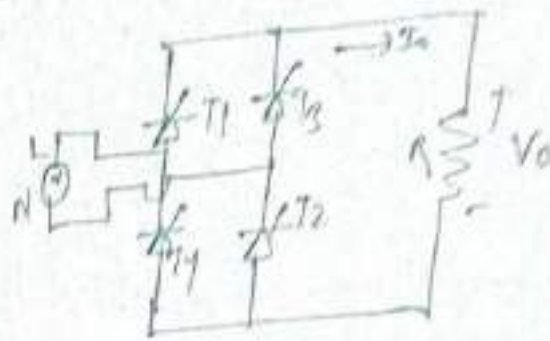
At $\omega t = \alpha$, T_2 is turned off and it remains reverse biased from $\omega t = \alpha$ to $\omega t = \pi$.

So circuit turn-off time = $t_c = \frac{\pi \alpha}{\omega}$



$$V_o = \frac{1}{\pi} \int_{\alpha}^{\pi + \alpha} V_m \sin \omega t \, d\omega t = \frac{2V_m}{\pi} \cos \alpha$$

Single phase full converter (B-2 connection) with freewheeling diode

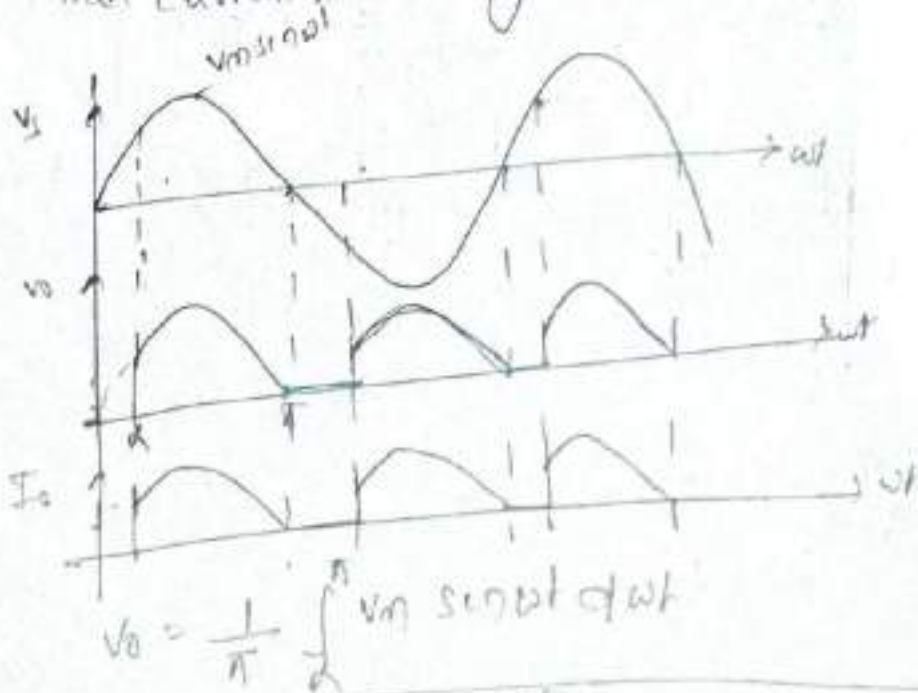


During +ve half cycle

T_1 & T_2 are forward biased. If both are triggered simultaneously, then current flows from $R \rightarrow T_1 \rightarrow R \rightarrow T_2 \rightarrow N$.

During -ve half cycle

T_3 & T_4 are forward biased. If they are triggered at same firing angle, then current flows through the path $R \rightarrow T_3 \rightarrow R \rightarrow T_4 \rightarrow N$.



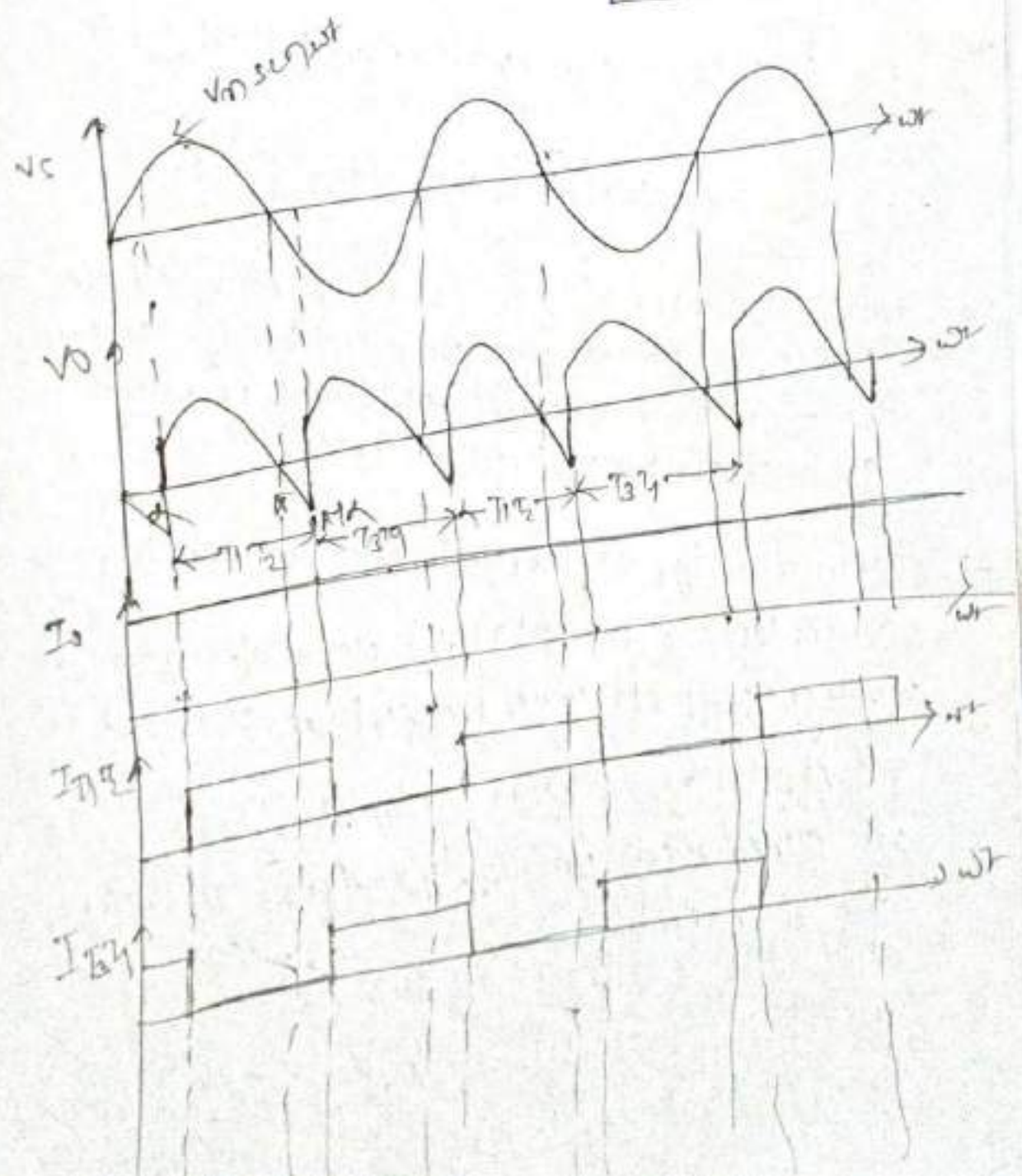
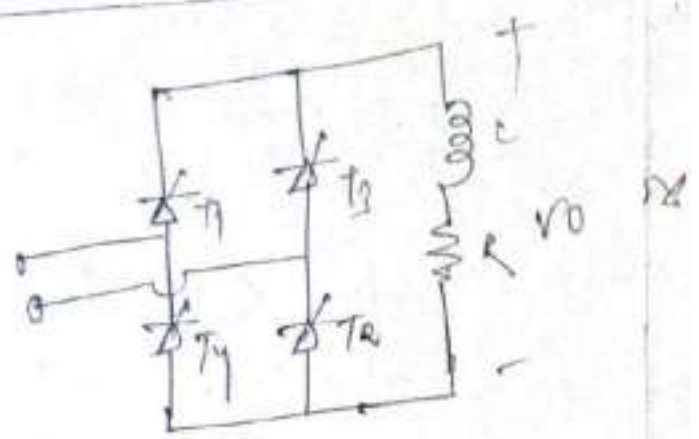
$$V_o = \frac{1}{\pi} \int_0^{\pi} v_m \sin \omega t \, d\omega t$$

$$V_o = \frac{v_m}{\pi} \int_0^{\pi} (-\cos \omega t) \, d\omega t = \frac{v_m}{\pi} (1 + \cos \alpha)$$

$$I_0 = \frac{V_0}{R}$$

(58)

fully controlled bridge circuit with R-L load



$$V_{00} = \frac{1}{\pi} \int_0^{\pi} V_m \cos \omega t d\omega = \frac{2V_m \cos \alpha}{\pi}$$

$$V_0 = \frac{2V_m \cos \alpha}{\pi}$$

$$I_0 = \frac{V_0}{R}$$

note if $\alpha < 90^\circ$ then it's rectification mode
if $\alpha > 90^\circ$ then it's Inverter mode

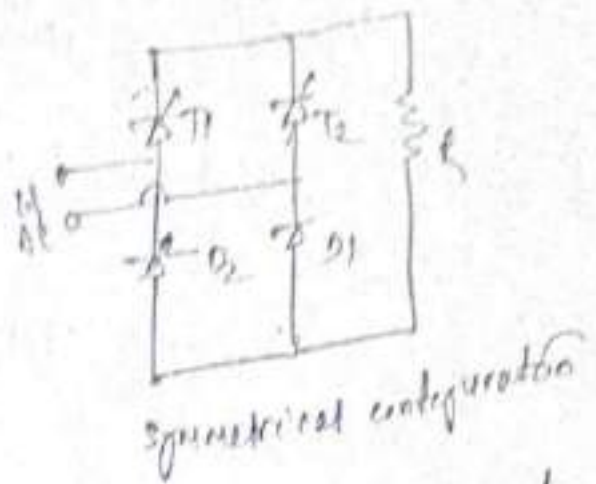
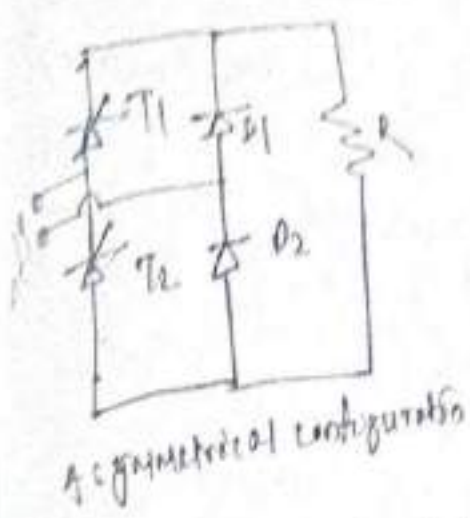
exer 10 Full wave converter with RL load & FD

Single phase half controlled bridge rectifier

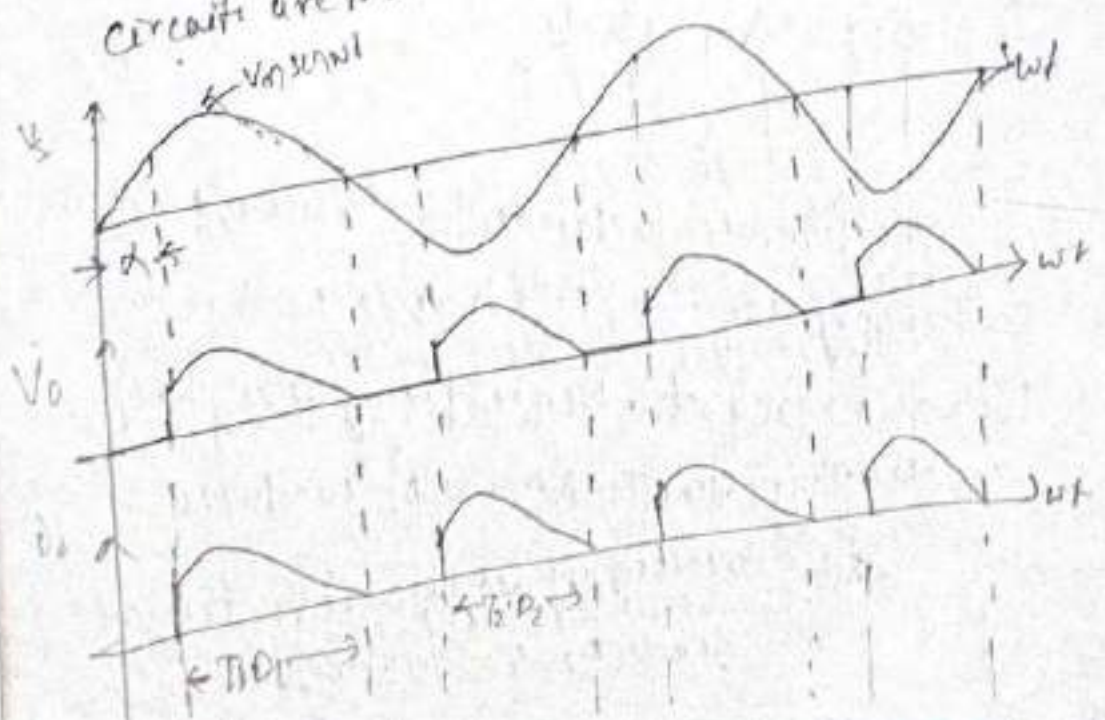
→ When one pair of SCR is replaced by diodes in single phase fully controlled bridge circuit, the resultant circuit obtained is called a half controlled bridge circuit.

→ With this type of circuit, it is possible to provide a continuous control of the mean d.c. terminal voltage from maximum to virtually zero, but reversal of the mean voltage is not possible. In other words only ^{one} quadrant operation can be obtained.

Half controlled bridge Rectifier with resistive load



- ⇒ In symmetrical configuration, the cathode of two SCR are at the same potential, so their gates can be connected and a single gate pulse can be used for triggering either SCR. The SCR which is forward biased at the instant of firing will turn on.
- ⇒ In asymmetrical configuration, separate triggering circuits are to be used.



Average dc load voltage (6)

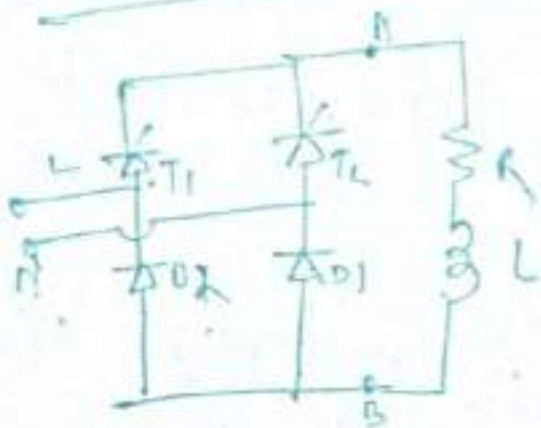
$$V_{dc} = \frac{1}{\pi} \int_{\pi}^{2\pi} v_m \sin \omega t \, d(\omega t)$$
$$= \frac{1}{\pi} v_m \left[-\cos \omega t \right]_{\pi}^{2\pi} = \frac{v_m}{\pi} \text{ (1st load)}$$

$$V_{dc} = \frac{V_H}{\pi} \text{ (1st load)}$$

Average load current

$$I_{dc} = \frac{V_{dc}}{R} = \frac{V_H}{\pi R} \text{ (1st load)}$$

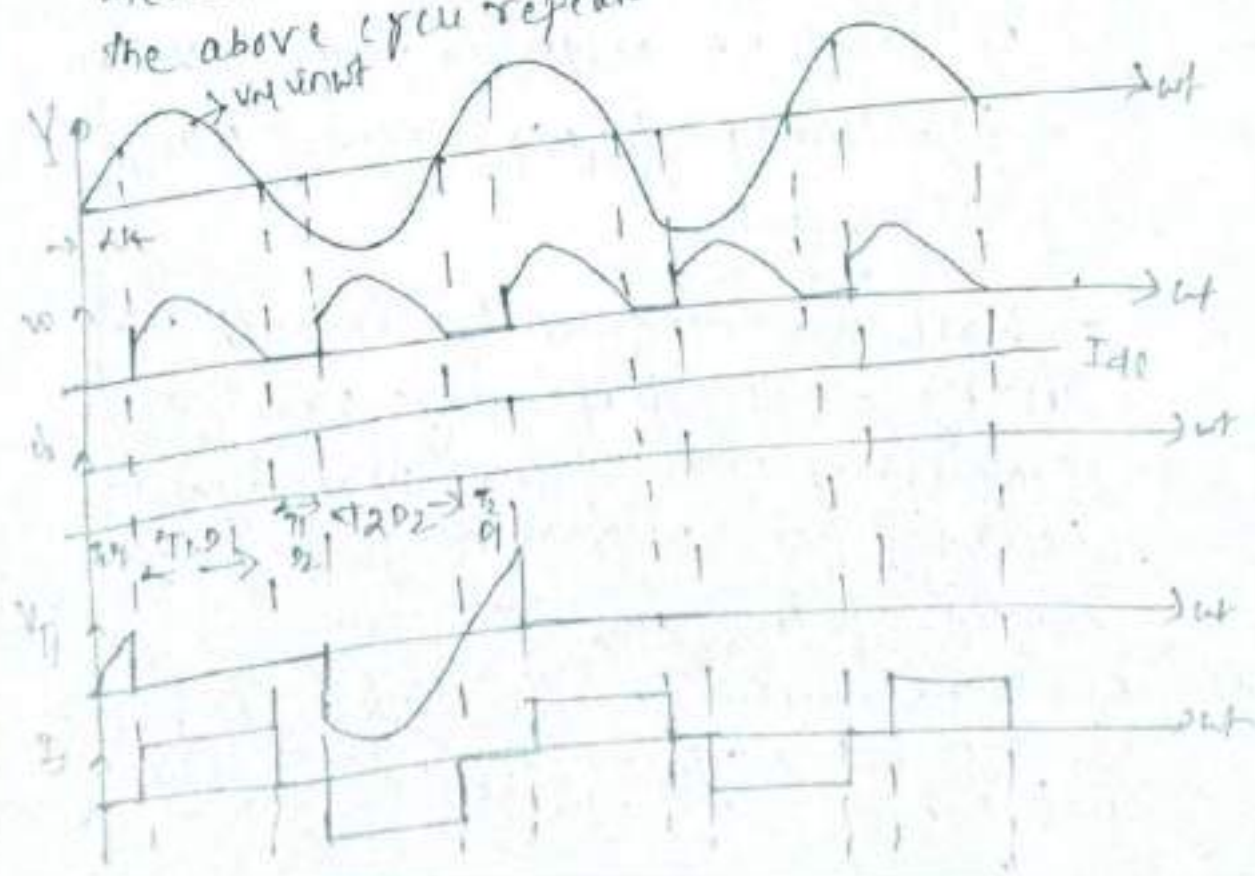
Half controlled Bridge Rectifier with R-L load



Here the filter inductance L is assumed to be sufficiently large as to produce continuous load current. Hence during +ve half cycle Thyristor T_1 & Diode D_1 conducts.

→ Now when the supply voltage reverses at $\omega t = \pi$, the diode D_2 is forward biased.

- 1) since D_1 is already conducting.
- 2) The Diode D_2 then turns on & the load current passes through D_2 & T_1 . The supply voltage reverse biases D_1 & turns it off.
- 3) Thus, the load current free wheels through the path $R-B-D_2-T_1-A-L$ during the interval from π to $(\pi + \alpha)$ in each supply cycle.
- 4) During the -ve half cycle at the instant $(\pi + \alpha)$ a triggering pulse is applied to the forward biased thyristor T_2 . Thyristor T_2 is turned on. As thyristor T_2 is turned on, the supply voltage reverse biases T_1 & then turns it off by the line commutation. Therefore, the load current flows through T_2 & D_2 the above cycle repeats.



$$V_{dc} = \frac{1}{\pi} \int_{\alpha}^{\pi} V_m \cos \omega t d(\omega t) = \frac{V_m}{\pi} (\pi - \alpha) \quad (2)$$

- comparison b/w half controlled & pulse circuit that of fully controlled circuit.

(i) since half the thyristors are replaced by diodes, a half-controlled converter costs less than a fully controlled converter.

(ii) The periods of the negative voltage "swing" at the dc terminal obtained with fully controlled bridge circuit are replaced by "free wheeling" periods of zero voltage in half controlled circuit. The elimination of the negative swing of voltage at dc terminals is advantages because it results in reduction of ripple voltage. Also correspondingly reduced filtering requirement.

(iii) In half controlled bridge circuit the average dc terminal voltage can be continuously controlled from maximum to virtually zero with an increased control range of firing angle α .

(iv) Due to free wheeling action with half controlled bridge circuit, power factor is improved in half controlled converter.

1) The ac supply current is now distorted due to its zero periods with half controlled circuits, compared to fully controlled bridge circuit.

Power factor Improvement:

DATE: 03/09/19

- The supply power factor in phase controlled converter is low when the output voltage is less than maximum i.e. when the firing angle is large.
- The displacement angle b/w the supply voltage and current increases as the firing angle increases & the converter draws more lagging reactive power thereby decreasing the power factor.
- The poor power factor operation is a major concern in variable speed drives with high power applications.
- The various techniques to improve power factor in phase controlled converter are:

- ① phase angle control (PAC)
- ② semi-converter operation of full converter
- ③ asymmetrical firing

Phase angle control:

2) An alternator with fixed source voltage of 250V, delivers a power to a load. The transmission line reactance is 5Ω and load current is 20A. Calculate the load voltage, voltage regulation, % pf utilization and energy consumed for a load power factor of 0.8 unity.

The ac supply current is more distorted due to its zero periods with half controlled circuit, compared to fully controlled bridge circuit.

Power Factor Improvement:

DATE: 03/07/19

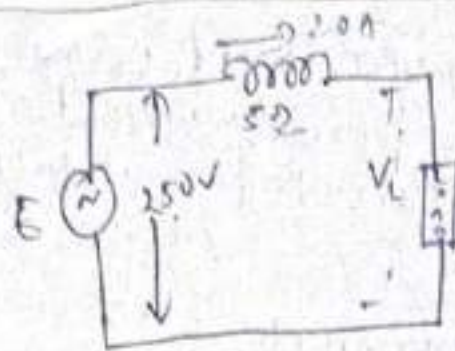
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Phase angle control:

Q. An alternator with fixed source voltage of 250V, delivers a power to a load. The transmission line reactance is 5Ω and load current is 20A. Calculate the load voltage, voltage regulation, system utilization and energy consumed for a load power factor of (a) unity (b) 0.8 lagging.

20/10



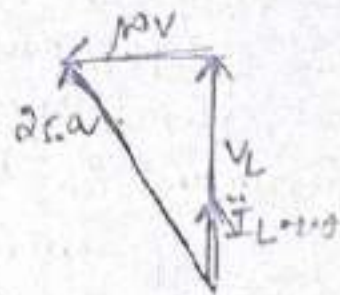
(65)

⊙ unity p.f

from fig $V_L^2 + I^2 R^2 = E^2$

$$\rightarrow V_L^2 = E^2 - I^2 R^2$$

$$V_L = \sqrt{250^2 - 100} = 229.13V$$



$$V.L = \frac{250 \times 229.13}{250} \times 100 = 5.35 \%$$

$$\text{Load power} = V_L I \cos \phi = 229 \times 20 \times 1 = 4582.6 \text{ W}$$

$$\text{Max}^m \text{ possible system rating} = 250 \times 20 \times 1 = 5000$$

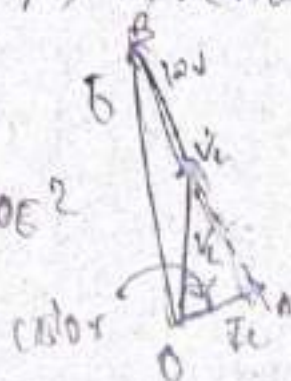
$$\text{system utilization factor} = \frac{4582.6}{5000} \times 100 = 91.65 \%$$

$$\text{Load energy delivered per hour} = \frac{4582.6}{1000} \times 1000 = 4582.6 \text{ kWh}$$

Assuming 5/- per unit, revenue earned = 4582.6 × 5/- = 22913/-

⊙ 0.5 p.f lag

$$\text{for } \phi \text{ lag } OA^2 + AB^2 = OE^2$$



= 23/-
per hour

$$(V_L \cos \theta)^2 + (V_L \sin \theta)^2 = 250^2$$

\downarrow 0.5 \downarrow 0.866

$$\Rightarrow \boxed{V_L = 158.35V}$$

$$V \cdot R = \frac{250 - 158.35}{250} \times 1W = 36.66\%$$

$$\text{Load power} = V_L I_L \cos \theta$$

$$= 158.35 \times 20 \times 0.5 = 1583.5 \text{ W}$$

$$\text{System utilization factor} = \frac{1583.5}{5000} \times 100 = 31.67\%$$

$$\text{Energy delivered to load per hour} = \frac{1583.5}{1000} = 1.58 \text{ kWh}$$

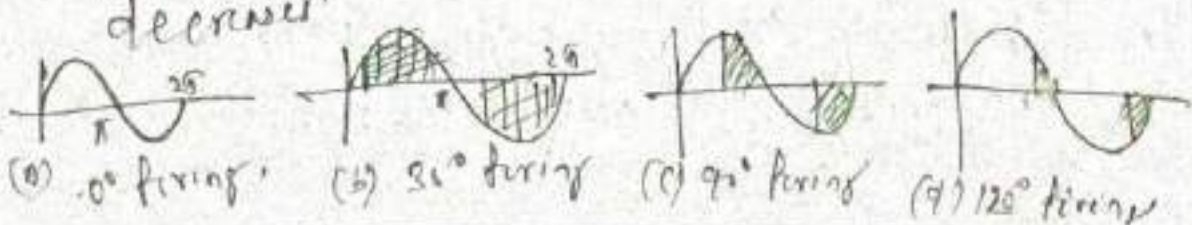
$$\text{Revenue earned per hour} = 1.58 \times 5 = 7.90 \text{ /- per hour}$$

→ The following methods are used to improve power factor in the phase controlled converter.

① Phase angle control

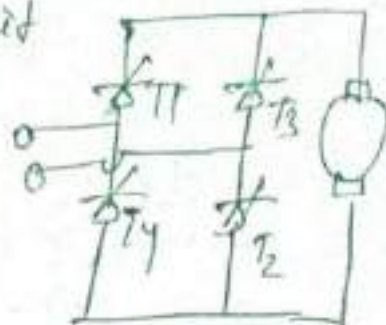
→ The output voltage decreases as the firing angle of SCR increases.

→ The i/p displacement factor wd input power factor decreases as the o/p voltage decreases.



(b) Semiconverter operation of full converter

The change in controlled circuit is necessary in order to operate semiconverter in full converter.



(1) Rectifier mode

→ SCR T_1 & SCR T_2 → act as switches

→ output voltage is adjusted by controlling the firing angle of T_1 & T_2 .

→ The firing of T_1 & T_2 is kept at zero when $\alpha = 0^\circ$ for T_1 & T_2 of o/p voltage = Max^m & when $\alpha = 180^\circ$ then o/p = 0V.

(2) Inverter mode

T_1 & T_2 → act as switches

T_3 & T_4 → firing angle is adjusted to get the o/p voltage.

→ The firing angle of positive group T_1 & T_2 is kept at 180° .

→ When the firing angle of negative group of SCR T_3 & T_4 is kept at 180° → o/p voltage = Max^m

∴ the o/p voltage is zero if $\alpha = 0^\circ$.

→ Actually the firing angle is kept less than 180° in order to keep commutation margin.

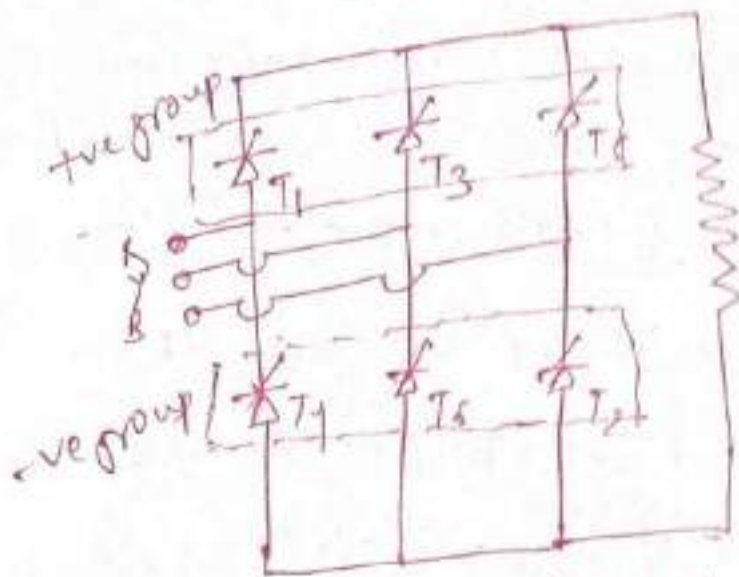
A symmetrical firing

- The firing angle of SCR is kept same in symmetrical firing whereas in asymmetrical firing, firing angle is kept different
- Let us consider that the firing of SCR₁ is kept at 60° & SCR₂ is kept at 120° in the asymmetrical firing angle control.
- The power factor improves to some extent when firing angle of T₁ is kept small.

disadv

- (A) It generated 2nd, 4th, 6th harmonics
- (B) The motor current is dis continuous.
- The power factor of forced commutated converter is done by following method
 - (a) Extinction angle control (EAC)
 - (b) symmetrical angle control
 - (c) pulse width modulation method.

3φ fully controlled Rectifier with R Load



$$\frac{2\pi}{6} = 60^\circ$$

→ For con pulse operation, each cell is to be fired twice in its conduction cycle so that firing interval is 60° .

(1) continuous conduction mode: ($\cos \alpha < \pi/3$)

$$V_{avg} = \frac{1}{\left(\frac{2\pi}{6}\right)} \int_{\pi/4}^{\pi/2 + \alpha} V_m \sin \omega t \, d(\omega t)$$

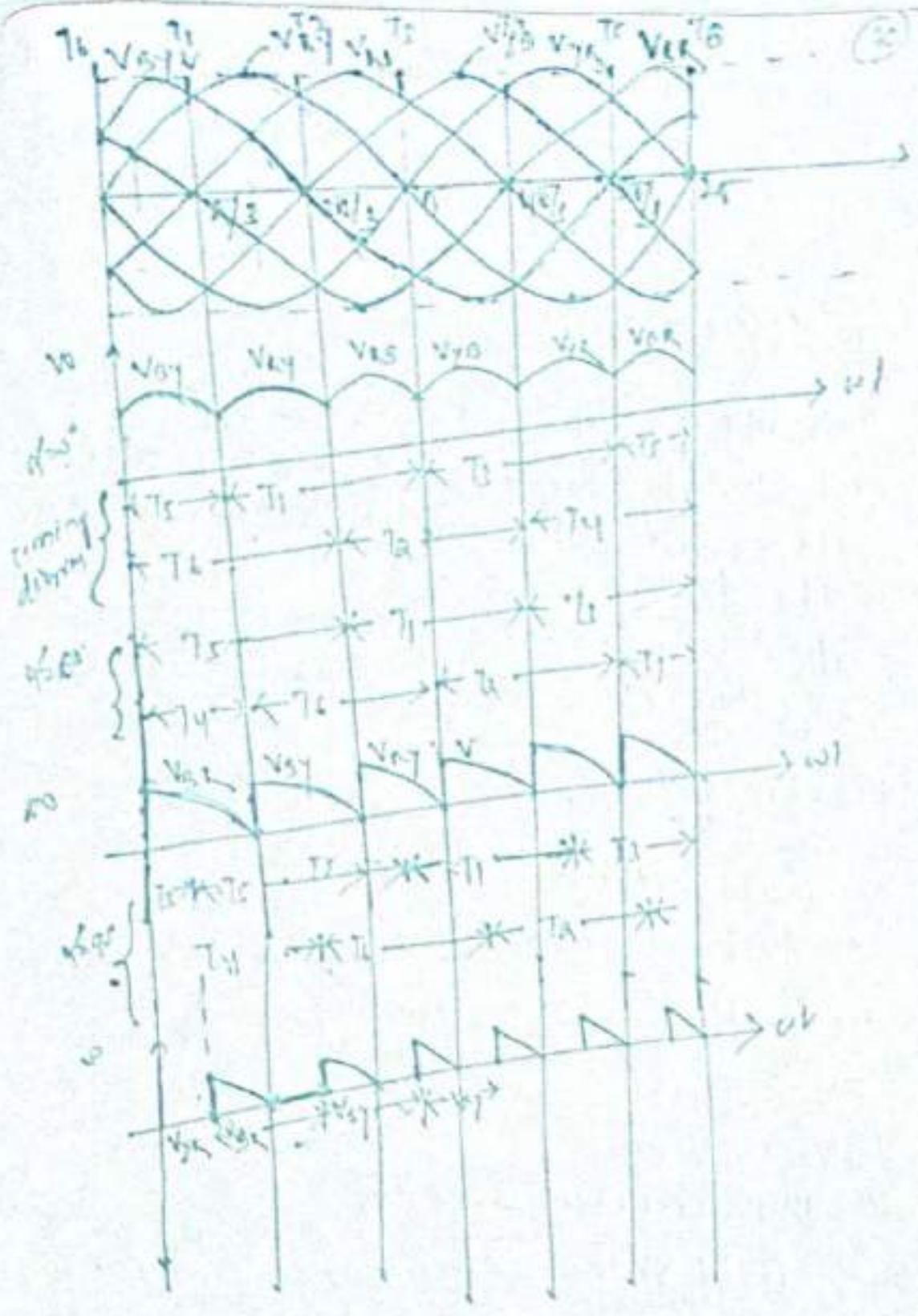
$$V_o = \frac{3V_m \cos \alpha}{\pi}$$

$$V_o = \frac{2V_m}{\pi}$$

(2) discontinuous conduction mode: $\alpha > \pi/3$

$$V_o = \frac{1}{\pi} \int_{\pi/3}^{\pi/2 + \alpha} V_m \sin \omega t \, d(\omega t)$$

$$= \frac{3V_m}{\pi} \left[\frac{1}{3} \cos \left(\frac{\pi}{3} + \alpha \right) + \frac{1}{3} \cos \left(\frac{\pi}{2} + \alpha \right) \right]$$



Introduction

Inverter

(31)

Dc power \rightarrow Ac power at desired o/p voltage & frequency.

For low and medium power output \rightarrow BJT, MOSFET, IGBT, GTO, etc

For high power o/p \rightarrow thyristor

\rightarrow The dc power i/p to the inverter may be battery, fuel cell, solar cells or other dc source. But in most industrial applications it is fed by a rectifier. This configuration of ac to dc converter & dc to ac inverter is called a dc link.

Application of Inverter

- \rightarrow variable speed ac motor drive
- \rightarrow induction heating
- \rightarrow Aircraft power supplies
- \rightarrow UPS
- \rightarrow HVDC
- \rightarrow Battery vehicle drives
- \rightarrow Regulated voltage & frequency power supplies

Classification of converter:

① classification according to nature of input source:

- ① voltage source inverter
- ② current source inverter

in case VSI, the IFF to the inverter is provided by
ripplefree dc voltage source whereas in CSI, voltage source
is first converted into current source and then used
to supply the power to the inverter

(6) Classification according to the waveform of
the output voltage:

- (1) Square wave inverter
- (2) Quasi square wave inverter
- (3) Pulse width modulated inverter
↳ high power application

(7) According to method of commutation

- (1) Line commutated inverter
- (2) Forced " "

(8) According to connections:

- (1) Series inverter
- (2) Parallel inverter
- (3) Bridge inverter
 - (1) half bridge
 - (2) Full bridge

(73)

AC voltage controller or AC regulator

fixed AC \longrightarrow Variable AC
(fixed frequency)

application

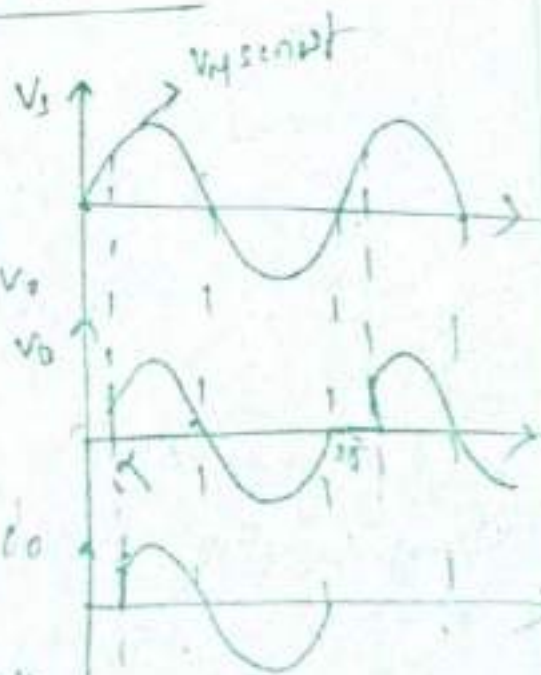
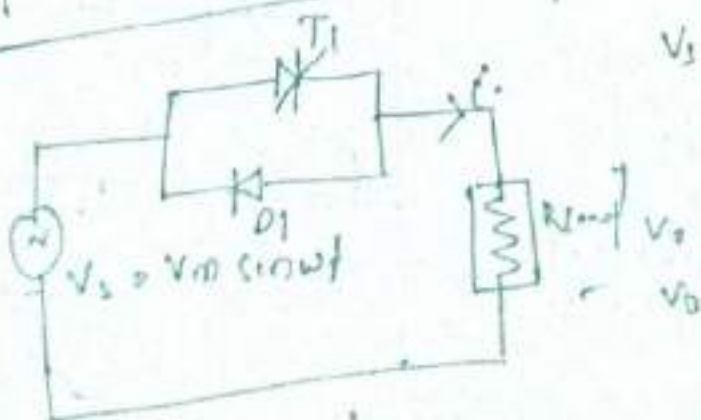
- (i) speed control of polyphase Induction Motor
- (ii) domestic & industrial heating
- (iii) light control
- (iv) on-load transformer tap changing
- (v) static Reactive power compensator etc.

Classification

① half wave ac regulator

② full wave ac regulator

1. half wave ac voltage regulator with R-load.



\rightarrow Since the power flow is controlled during the +ve half cycle of i_T , so this type of controller is also known as unidirectional controller.

→ This type of controller is only suitable for low power resistive load such as heating & lighting

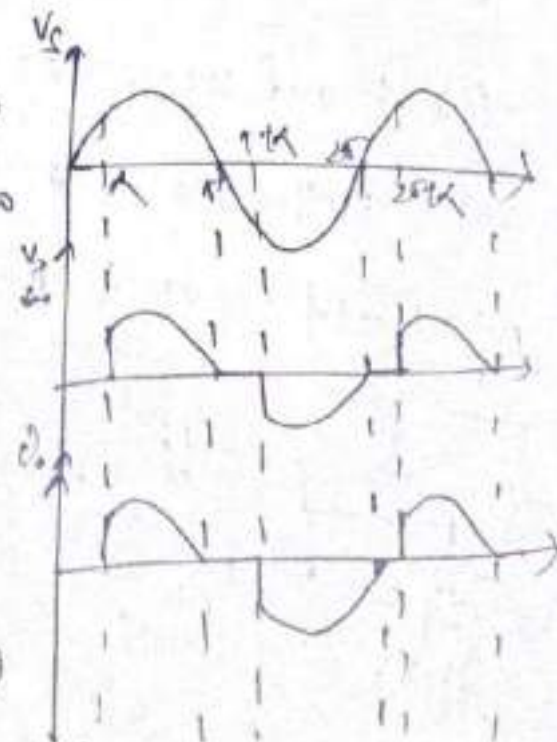
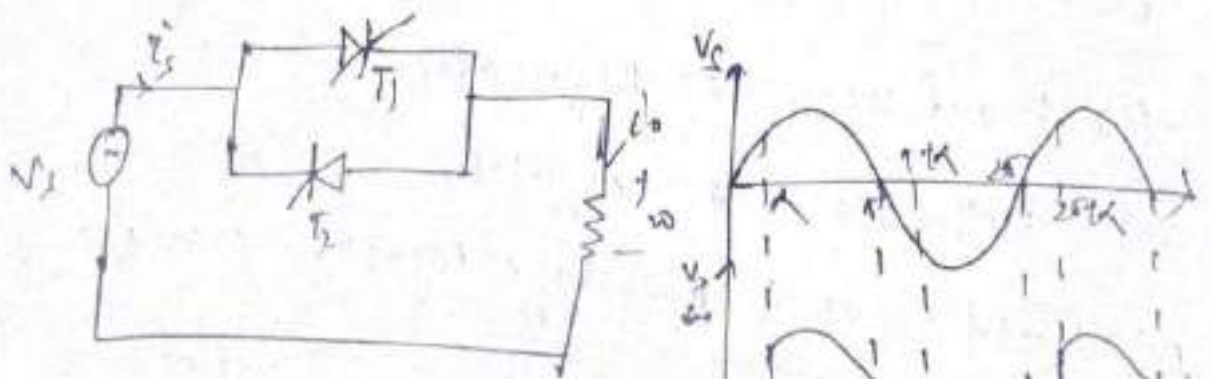
$$V_o = \frac{1}{2\pi} \int_{\alpha}^{2\pi} V_m \sin \omega t \, d(\omega t)$$

$$V_o = \frac{V_m}{2\pi} (\cos \alpha - 1)$$

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

$$I_s = I_o = \frac{V_m}{2\pi R} (\cos \alpha - 1)$$

Full wave ac voltage regulator



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

$V_o \neq 0$

(symmetrical waveform)

$$V_{orms} = \left[\frac{1}{\pi} \int_{\alpha}^{2\pi} V_m^2 \sin^2 \omega t \, d(\omega t) \right]^{1/2}$$

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

SMPS

↳ Switch Mode power supply

- In SMPS Transistor operate in the switch at very high frequency, at such a high frequency we can reduce the size of transformer as well as the filter size. Therefore SMPS is highly efficient & compact in size.
- For high frequency transformer used in SMPS we use ferrite core to reduce the core loss.
- With the availability of high speed device like power MOSFET SMPS is popularly used now a days.

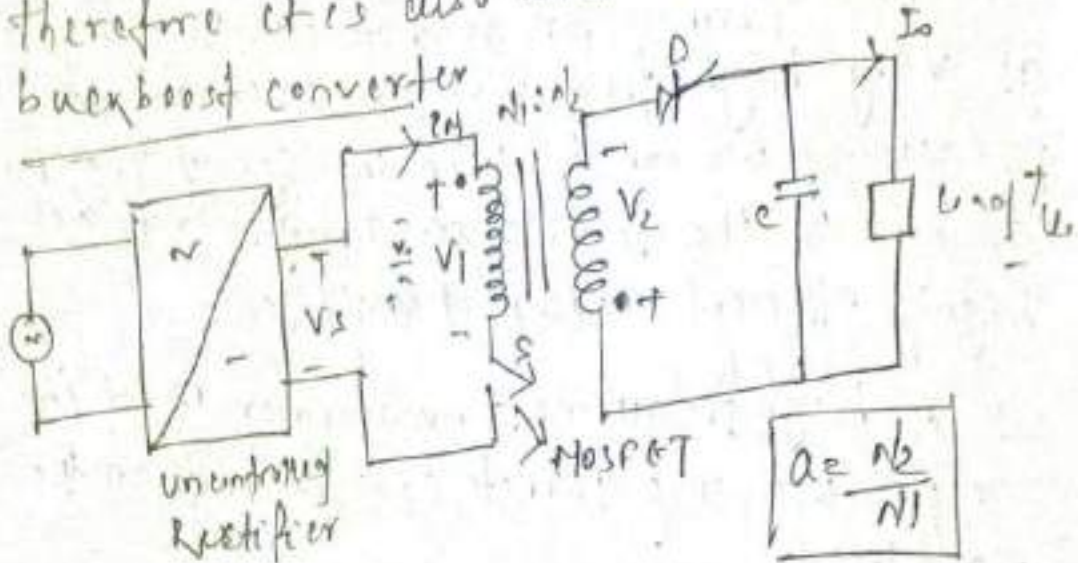
Types of SMPS

→ The circuit techniques used for SMPS can be separated into following four broad categories.

- (1) Flyback SMPS
- (2) Forward SMPS
- (3) Push pull SMPS
- (4) Bridge SMPS.

① Flyback converter

It is derived from a buck boost converter, therefore it is also known as isolated buck boost converter



(I) $0 \leq t \leq T_{on}$

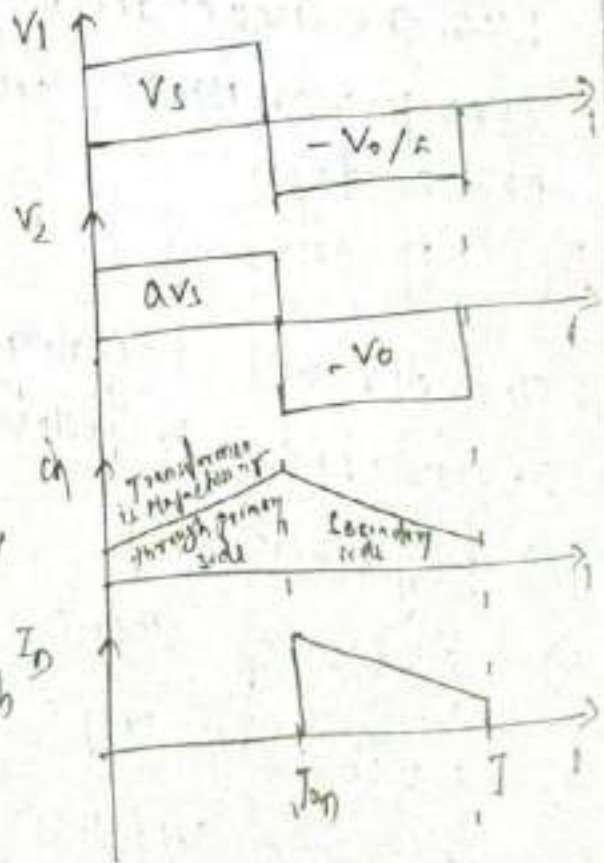
$S \rightarrow ON, D \rightarrow off$

$\rightarrow V_1 = V_s$

$$V_a = \frac{n_2}{n_1} V_1$$

$$V_2 > aV_s$$

\rightarrow In this mode transformer stores energy through primary side i.e. it is magnetized through primary side.



(II) $T_{on} \leq t \leq T$

When the switch is off inductor changes its polarity so V_a in secondary side changes its polarity & forward bias the diode. So when turn off the switch magnetizing current can flow in the

primary side, so has to flow on the secondary.

$S \rightarrow$ off, $D \rightarrow$ on.
 So in this mode T1 is releasing energy through secondary side the di is demagnetizing through the secondary side

$$V_2 = -V_0$$

$$V_1 = \frac{n_1}{n_2} V_a$$

$$V_1 = -\frac{V_0}{a}$$

avg o/p voltage

$$V_0 = \frac{a d V_s}{1-d}$$

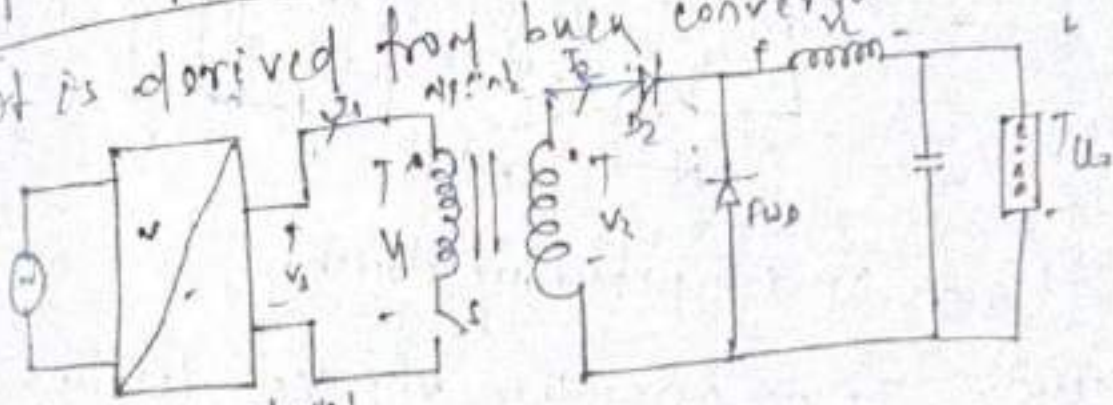
The peak forward blocking capacity of switch $\approx V_s + \frac{V_0}{a}$

PIV of diode $\approx a V_s + V_0$

used below about now

forward converter

it is derived from buck converter



I Mode ($0 < t < T_{on}$)

$S_1 \rightarrow$ on, $D_2 \rightarrow$ on

$V_1 = V_s$ - V_L in secondary

$$V_a = \frac{n_1}{n_2} V_s$$

$$V_L = a V_s$$

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

$$V_L = V_0 - V_0$$

$$V_L = a V_s - V_0$$

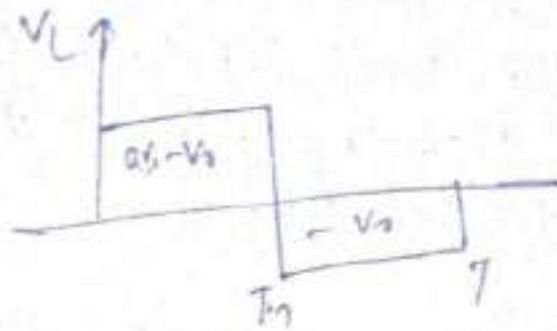
II mode ($T_{on} < t < T$)

when S_1 off
 $I_L = 0$ to I_{D2}
 so S_1 off $\rightarrow D_2$ on
 so current free wheel through D_2 .

$$V_L + V_0 = 0$$

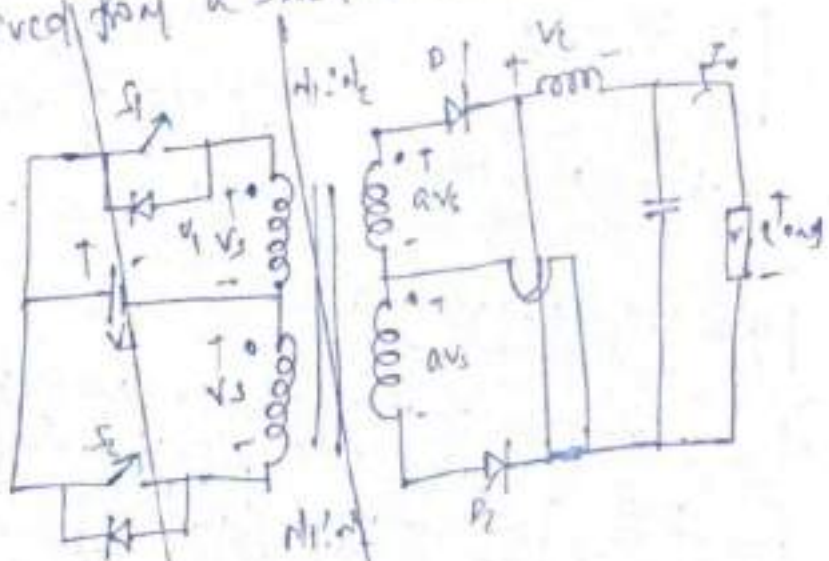
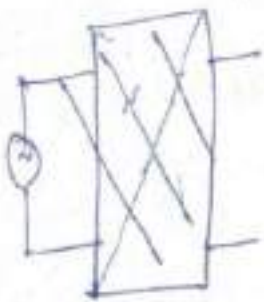
$$\Rightarrow V_L = -V_0$$

Average o/p voltage V_o or aV_s . (75)



③ Pushpull Converter

It is derived from a buck converter.



S_1 & S_2 are complementary switches.

(1) Mode 1 (S_1 is on) then $V_1 = V_c$ develops on upper half of primary.

So corresponding $V_2 = aV_s$ developed

in the secondary & hence forward bias diode D_1 in the load current flow through load.

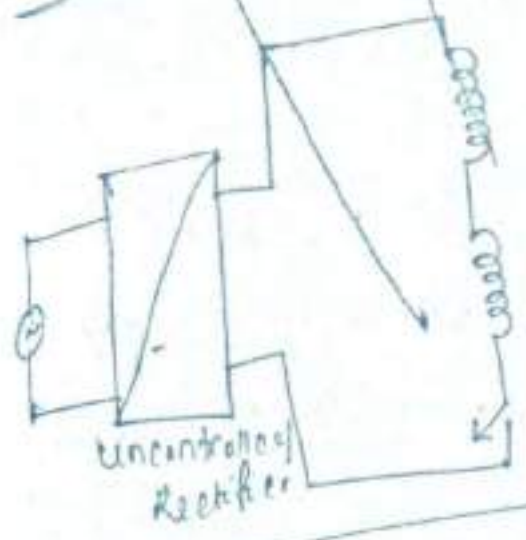
Applying KVL

$$-aV_s + V_c + V_o = 0$$

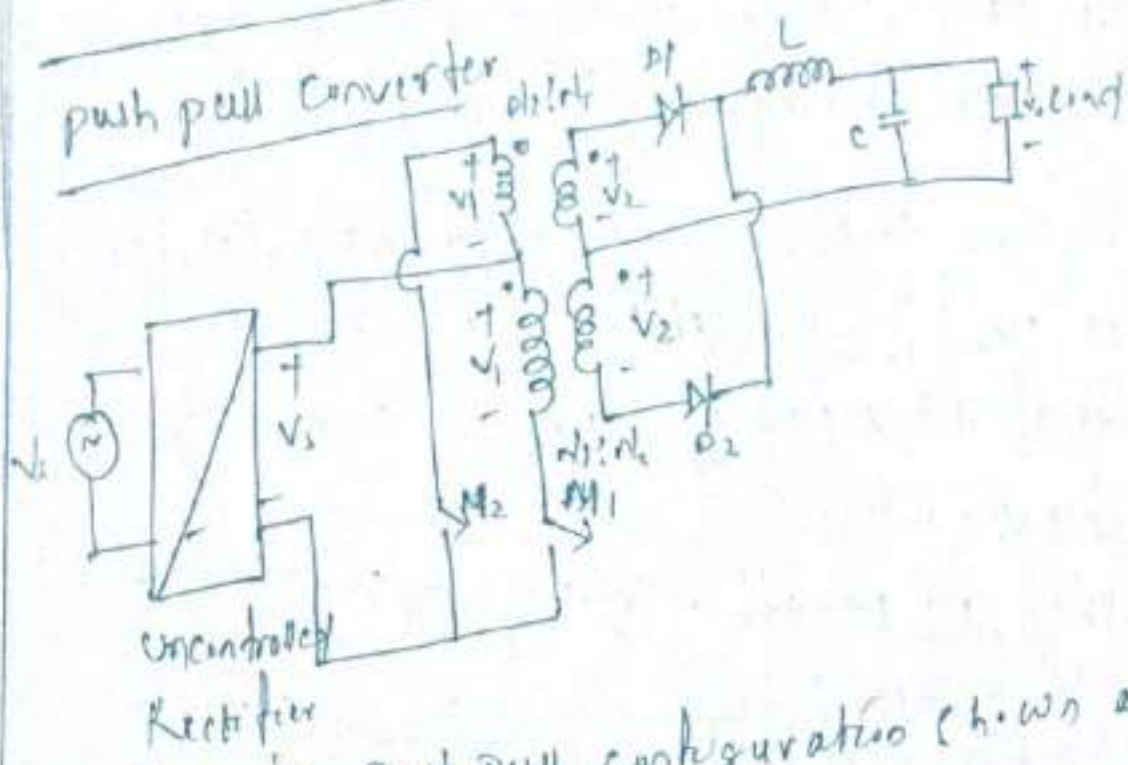
$$\Rightarrow V_c = aV_s - V_o$$

Q8 starts

push pull converter:



push pull converter



SMPS with push pull configuration (shown above) it uses two power MOSFET M_1 & M_2 and a transformer with mid taps on both primary and secondary sides. When M_1 is turned on, V_1 is applied to lower half of transformer primary i.e. $V_1 = V_s$. As a result $V_2 = \frac{N_2}{N_1} V_s$ is induced in both secondary

voltage v_a on upper half is secondary forward biased diode D_1 , therefore load voltage v_o is given by

$$V_o = \frac{V_s n_2}{n_1} = aV_s$$

when M_2 is turned on, $v_1 = -v_s$ is applied to upper half of primary winding consequently

$v_2 = -\frac{v_s n_2}{n_1}$ is induced in both transformer

secondaries. As v_a is $-v_1$, diode D_2 gets forward biased and $V_o = aV_s$

→ This shows that voltage on primary swings from $+v_s$ with M_1 on to $-v_s$ with M_2 on.

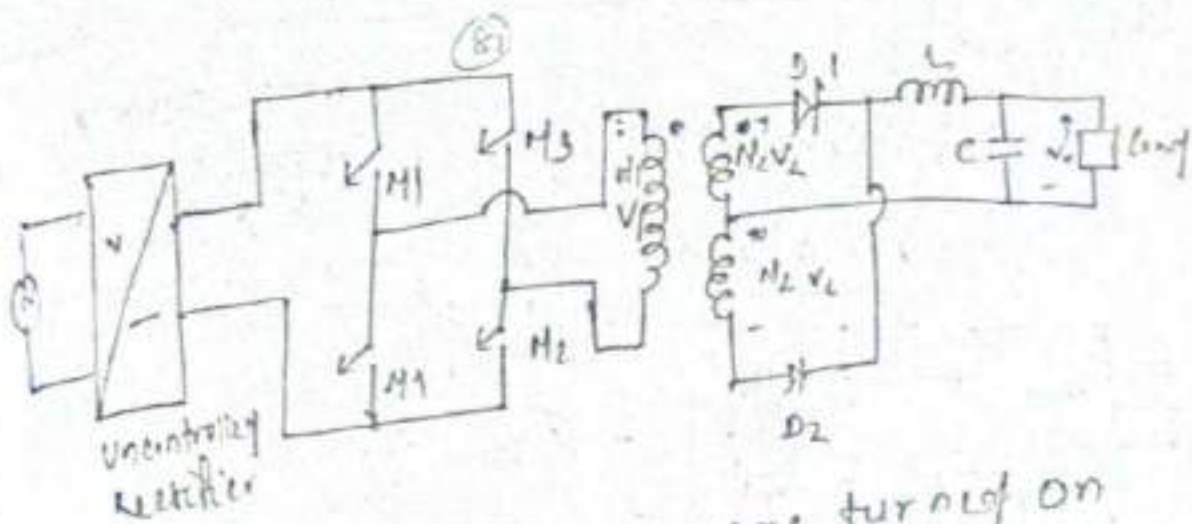
power MOSFETs M_1 & M_2 operates with duty

$$\text{cycle } d = 0.5$$

→ When M_1 is off, voltage across M_1 terminal is $V_{ce} = 2aV_s$

Full Bridge Converter:

→ It consists of an uncontrolled rectifier four power MOSFETs, transformer with mid-tap secondary, two diodes and LC filter



When power MOSFET M_1 & M_2 are turned on together, voltage V_1 appears across transformer primary i.e. $V_1 = V_s$ and secondary voltage $V_2 = \frac{n_2}{n_1} V_s = aV_s$. Diode D_1 gets forward biased and $V_o = aV_s$.

→ When M_3 & M_4 turned on together the primary voltage is reversed i.e. $V_1 = -V_s$ and $V_2 = -aV_s$, therefore diode D_2 now begins to conduct and o/p voltage is again $V_o = aV_s$.

Advantage of SMPS over conventional linear power supplies

→ For same power rating, SMPS is of smaller size & lighter in weight and possesses higher efficiency because of its high frequency operation.

→ SMPS is less sensitive to i/p voltage variation.

Disadvantage of SMPS

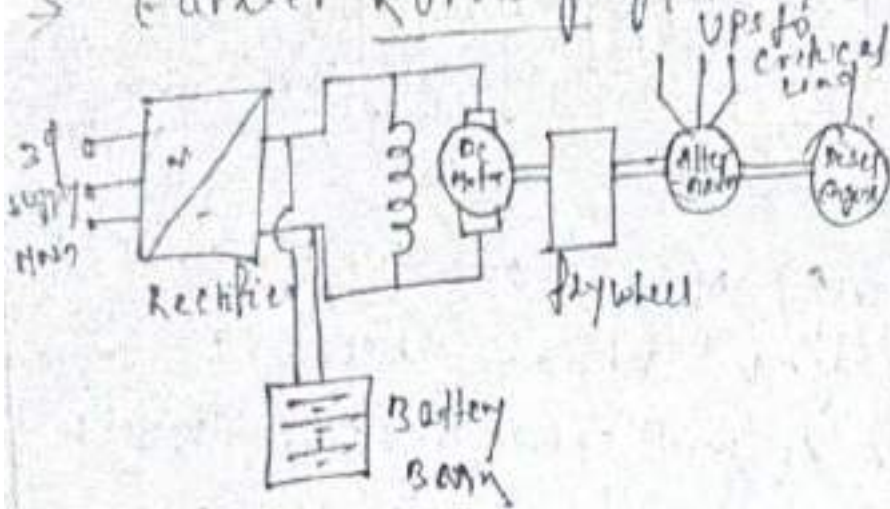
→ SMPS has higher o/p ripple and its regulation is worse.

→ SMPS is a source of both electromagnetic & radiative interference due to high frequency switching.

→ Control of radio frequency noise requires filters on L & C components.

UPS
↳ Uninterruptible power supply

→ Earlier Rotating type UPS were used.



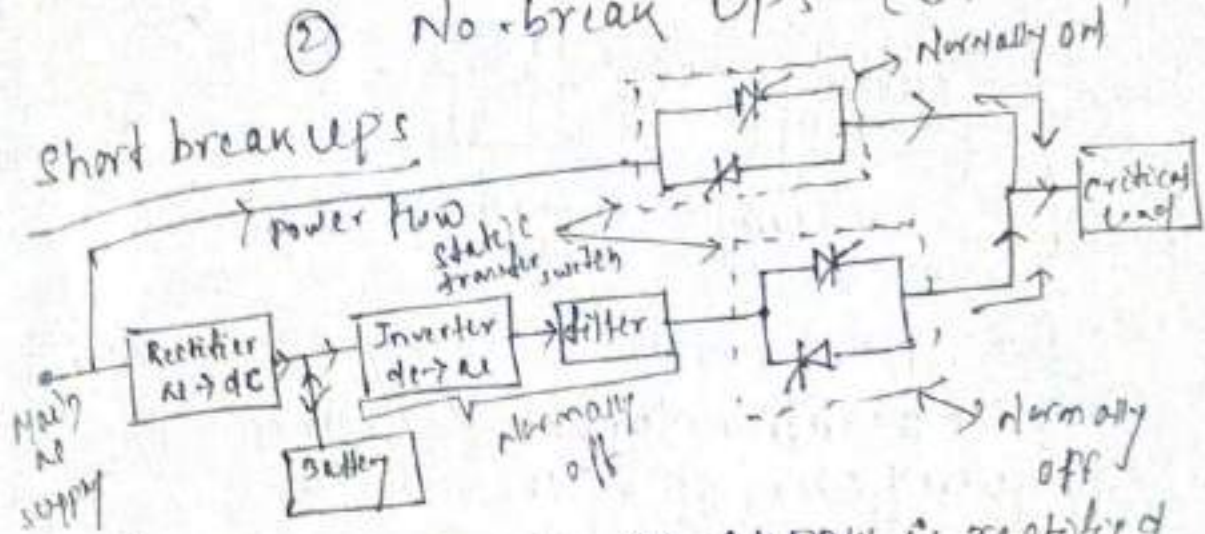
→ This arrangement consists of DC motor driven alternator, the shaft of which is also coupled to a Diesel engine.

→ The three phase Mains supply after rectification charges a dc battery bank and feeds the dc motor as well. The uninterruptible power supply needed is taken from the alternator O/P terminal.

→ When Mains supply fails, the diesel engine is run to take over the load. Starting of diesel engine takes 10 to 15 sec. During this period, battery bank is able to maintain the alternator speed through the dc motor and flywheel thus giving no break supply to critical load.

Static UPS systems are of two types

- ① short break UPS (4 to 5 ms)
- ② No-break UPS (no interruptions)



→ In this system main ac supply is rectified to dc. The dc output from rectifier charges the battery and is also converted to ac by an inverter.

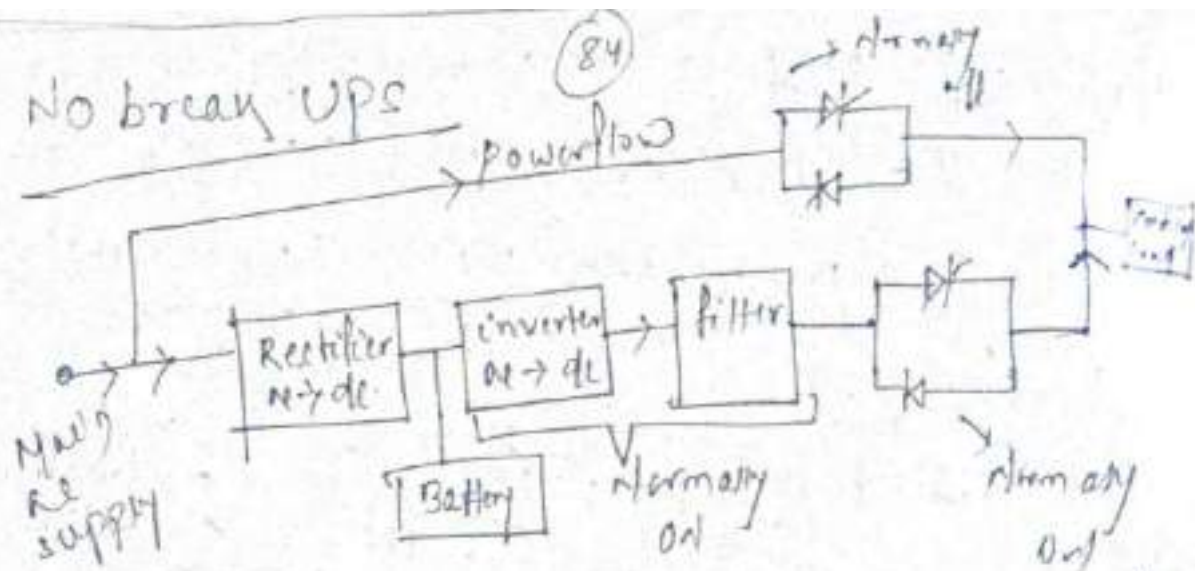
→ After passing through the filter, ac can be delivered to load in case normally off contacts are closed.

→ Under normal situation power flow through normally on switch to critical load. At the same time battery gets charged.

→ In the event of power outage, normally off switch is turned on and battery deliver ac power to critical load through inverter and filter.

1. This type of arrangement is also called Standby power supply.

No break UPS



→ In this system, main ac supply is rectified and the rectifier delivers power to maintain required charge on the batteries.

→ Rectifier also supplies power to inverter continuously which is then given to ac type load through filter & normally on switch.

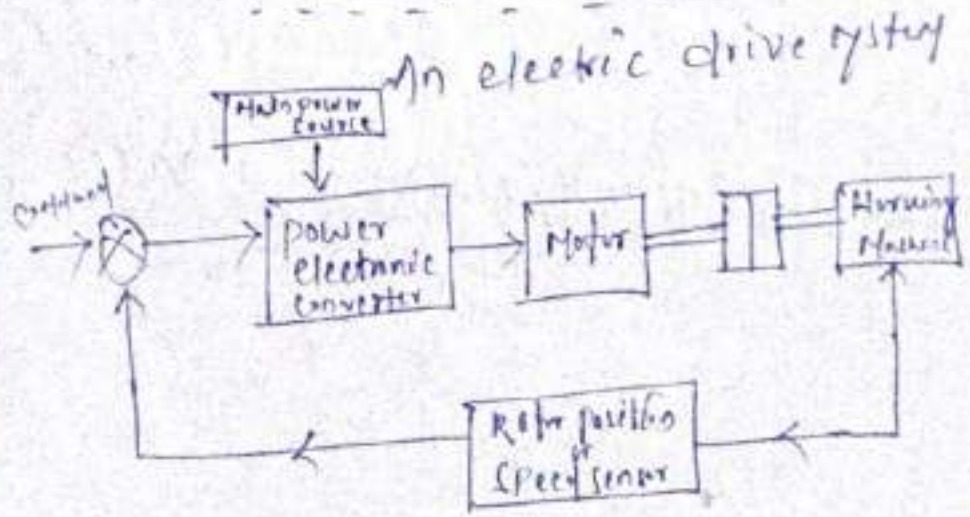
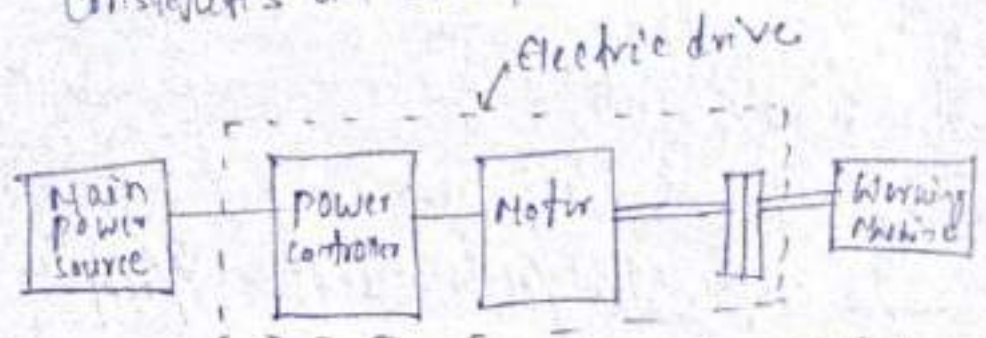
→ In case of main ac supply failure, battery at once take over with no break of supply to critical load. No dc's continuity in the illumination is observed in case of no break UPS.

→ In case of inverter failure is detected, the load is switched on to main ac supply direct by turning on the normally off static switch and opening the normally on static switch.

AC & DC drives

A complete production unit consists primarily of three basic components: an electric motor, an energy transmitting device and the working machine.

- An electric motor together with its control equipment and energy transmitting device forms an electric drive.
- An electric drive with its working machine constitutes an electric drive system.



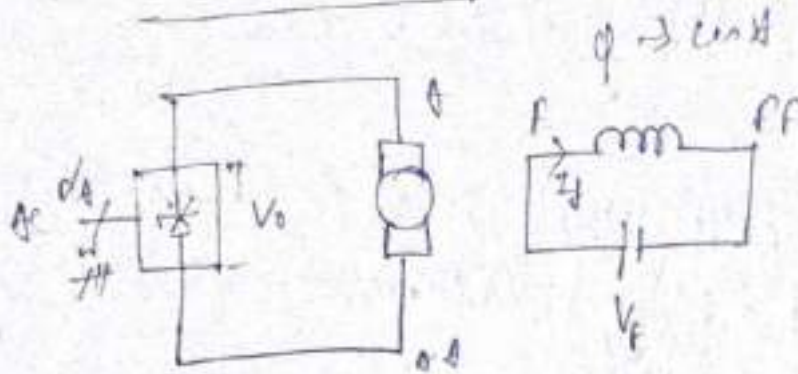
Modern ~~power~~ electric drive system using power electronic converter

dc drives

(86)

speed control

① Armature voltage control (ω < ω_m)



$$\text{If } V_a \propto \frac{\partial V_a}{\partial \alpha} \text{ then } \frac{\partial \phi}{\partial \alpha} \quad V_a = \frac{3V_m \cos \alpha}{\pi}$$

$$E_b \propto \phi N$$

$$E_b \propto N \quad (\text{since } \phi \rightarrow \text{const})$$

$$\boxed{E_b = k \omega} \rightarrow \text{Emf const / Motor const} \rightarrow \text{V/rpm}$$

$$\boxed{E_b = k \omega} \rightarrow \text{Emf const / Motor const} \rightarrow \frac{V \cdot \text{sec}}{\text{rad}}$$

$$T_a \propto \phi I_a$$

$$T_a \propto I_a \quad (\phi = \text{const})$$

$$\boxed{T_a = k I_a} \rightarrow \text{Torque const / Motor const} \rightarrow \frac{\text{Nm}}{\text{A}}$$

for Motoring Mode

$$V_0 = E_b + I_a R_a$$

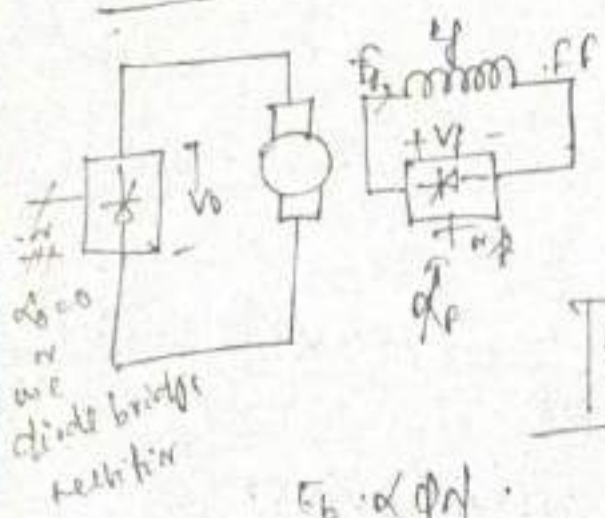
$$V_0 = k\omega + I_a R_a$$

$$\omega = \frac{V_0 - I_a R_a}{k}$$

$$\omega = \frac{V_0}{k} - \frac{R_a I_a}{k}$$

if $\alpha \uparrow \Rightarrow V_0 \downarrow \Rightarrow \omega \downarrow \Rightarrow \omega < \omega_{cr}$

Field control ($\omega > \omega_{cr}$)



$$I_f = \frac{V_f}{R_f}$$

$$\phi \propto I_f$$

$$\phi = k_f I_f$$

$$E_b \propto \phi \omega$$

$$\Rightarrow E_b = k_1 \phi \omega = k_1 k_f I_f \omega = k I_f \omega$$

$\left[\begin{matrix} \text{Field const} \rightarrow V \\ \omega \end{matrix} \right]$

$$E_b = k I_f \omega$$

$$\left[\frac{V \cdot \text{sec}}{\text{rads}} \right]$$

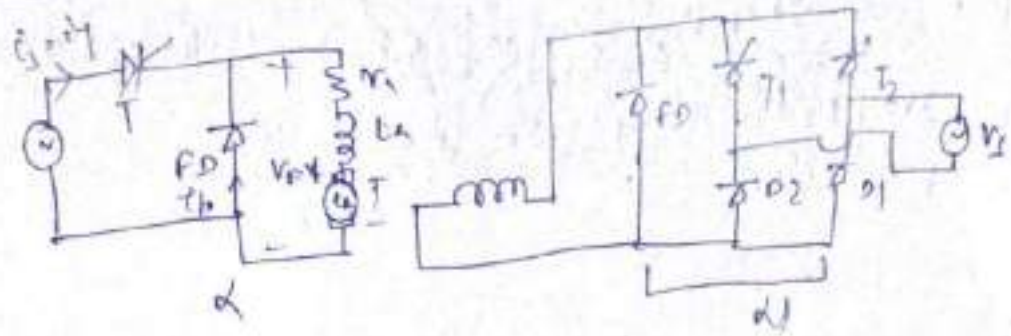
$$T \propto \phi I_a = k_1 k_f I_f I_a = k I_f I_a$$

for motoring mode

$$V_0 = E_b + I_a R_a = k I_f \omega + I_a R_a \Rightarrow \omega = \frac{V_0}{k I_f} - \frac{R_a I_a}{k I_f}$$

$\left[\begin{matrix} \text{Torque} \rightarrow \text{Nm/A} \\ \text{const} \\ \frac{V_0}{k I_f} - \frac{R_a I_a}{k I_f} \end{matrix} \right]$

1φ half wave converter dc drive (88)



- Separately excited dc motor fed through single phase half wave converter is shown.
- Motor field circuit is fed through a single phase semi-converter feeding a dc in order to reduce the ripple content in the field circuit.
- single phase half wave converter feed a dc Motor armature after one-quadrant drive.
- For single phase half wave converter, average o/p voltage of converter:

$$V_o = V_f = \frac{V_m}{2\pi} (1 + \cos \alpha) \quad \text{for } 0 < \alpha < \pi$$

$$V_f = \frac{V_m}{\pi} (1 + \cos \alpha) \quad 0 < \alpha < \pi$$

rms value of source thyristor current

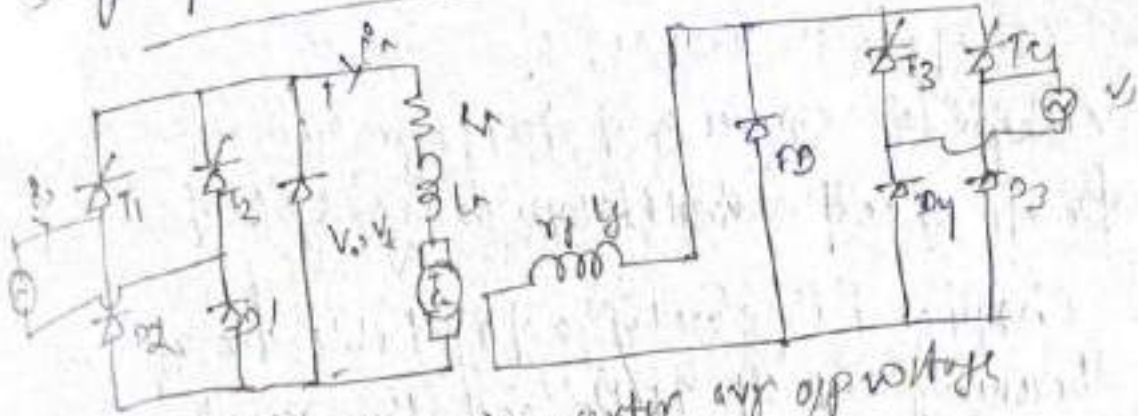
$$I_{or} = I_a \left(\frac{1 + \cos \alpha}{2} \right)^{\frac{1}{2}}$$

rms value of free wheeling diode current

$$I_{or} = I_a \left(\frac{1 + \cos \alpha}{2} \right)^{\frac{1}{2}}$$

output supply pf = $\frac{V_f I_a}{V_m I_{or}}$

single phase semi-converter drive (89)



for single phase semi-converter avg output voltage

$$V_0 = V_f = \frac{V_m}{\pi} (1 + \cos \alpha)$$

for field current $V_f = \frac{V_m}{\pi} (1 + \cos \alpha)$

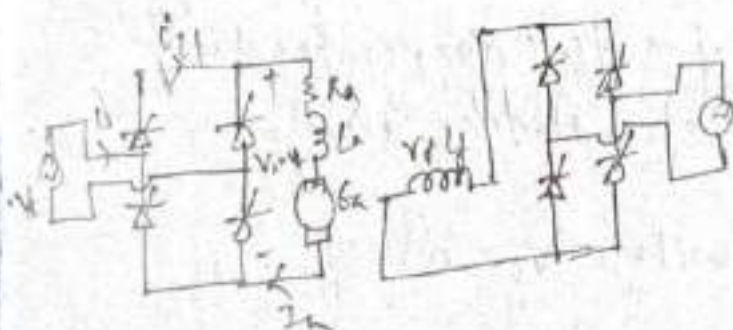
rms value of source current $I_{sr} = I_a \left[\frac{\pi}{\pi} \right]^{\frac{1}{2}}$

rms value of f.d current = $I_{for} = I_a \left[\frac{\pi}{\pi} \right]^{\frac{1}{2}}$

rms value of thyristor current = $I_{gr} = I_a \left[\frac{\pi - \alpha}{2\pi} \right]^{\frac{1}{2}}$

$$p.f = \frac{V_0 I_a}{V_{sr} I_{sr}}$$

single phase full converter drive



$$V_0 = V_f = \frac{2V_m}{\pi} \cos \alpha$$

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

rms value of source current $I_{sr} = I_a$

rms value of thyristor current = $\frac{I_a}{\sqrt{2}}$

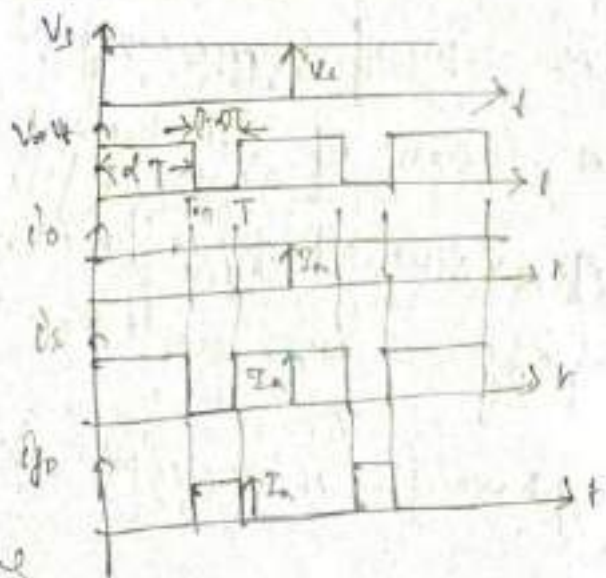
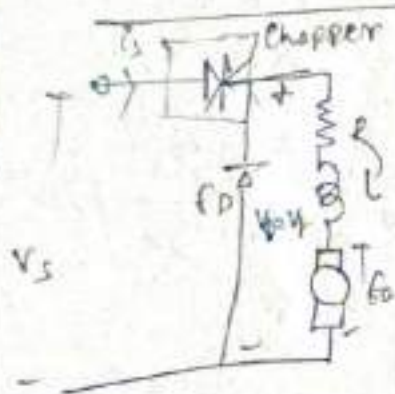
$$p.f = \frac{V_0 I_a}{V_{sr} I_{sr}} = \frac{V_0}{V_{sr}}$$

Chopper drive

(90)

- A chopper is inserted in between a fixed voltage dc source and dc motor armature for its speed control below base speed.
- Chopper is easily adaptable for regenerative braking of dc motor and thus kinetic energy of the drive can be returned to dc source.

Chopper drive used for single quadrant motoring control



- The above circuit diagram shows the basic arrangement of a dc chopper feeding power to a dc series motor.

Average motor voltage $V_o = \alpha V_s$

where $\alpha = \text{duty cycle} = \frac{T_{on}}{T}$

Power delivered to motor: $V_o I_a = \alpha V_s I_a$

Avg source current = αI_a

The equivalent resistance seen by source = $\frac{V_s}{I_s} = \frac{V_s}{\alpha I_a}$

input power to chopper $\stackrel{(91)}{=} V_s I_s = V_s (d I_a)$

for motor armature circuit $V_a = d V_s = E_b + I_a (r_a + r_s)$

$$d V_s = K_m \omega_m + I_a (r_a + r_s)$$

$$\Rightarrow \omega_m = \frac{d V_s - I_a (r_a + r_s)}{K_m}$$

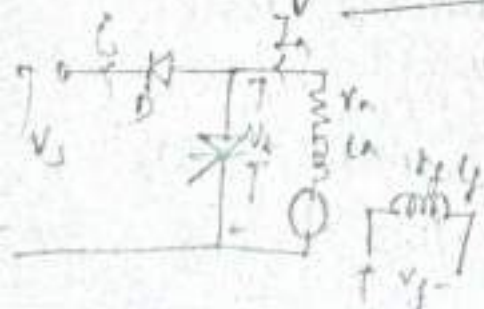
By varying duty cycle we can vary the speed of motor

chopper drive used for single quadrant regenerative braking control

→ In regenerative braking control, the motor acts as a generator and the kinetic energy of the motor and connected load is returned to supply.

→ During motoring mode $I_a = \frac{V_a - E_b}{r_a}$ i.e. armature current is +ve & motor consumes power.

→ In case of load drives the motor at a speed such that average value of motor counter emf exceeds $V_a \Rightarrow I_a$ reverses & power is delivered to dc source. Then the motor is working as generator in the regenerative braking mode.



→ For active load, such as a train going down the hill, $E_a > V_s$. When chopper is at current through armature inductance L_a rises as the armature terminal gets short circuit through chopper.

⇒ $V_b = 0$ during T_{on}

During T_{off} $E_a > V_s$ & diode conduct
 ⇒ $V_b = V_s$

$$V_b = (1-d)V_s$$

power generated by motor = $V_b I_a = (1-d)V_s I_a$

Motor emf generated $E_a = K_M \omega_M = V_s + I_a R_a$

Equivalent load resistance seen by the motor
 acting as a generator.

$$R_{eq} = \frac{E_a}{I_a} = \frac{(1-d)V_s + I_a R_a}{I_a} = (1-d) \frac{V_s}{I_a} + R_a$$

Motor speed during regenerative braking:

$$\omega_M = \frac{(1-d)V_s + I_a R_a}{K_M}$$

condition for controlling the power during regenerative braking is $E_a - I_a R_a > V_s$

Minimum braking speed obtained when $E_a - I_a R_a = 0$

$$\Rightarrow K_M \omega_{min} = I_a R_a \Rightarrow \omega_{min} = \frac{I_a R_a}{K_M}$$

(93)

maximum braking speed obtained when

$$I_a - I_a R_a = V_s$$

→ Max^m braking speed $\omega_{br} = \frac{V_s + I_a R_a}{K_{\omega}}$

→ Thus regenerative braking control is effective only when motor speed is less than ω_{br} i.e. $\omega < \omega_{br}$.

$$\Rightarrow \left[\frac{I_a R_a}{K_{\omega}} \right] < \omega < \left[\frac{V_s + I_a R_a}{K_{\omega}} \right]$$

MODULE-5

PLC AND ITS APPLICATIONS

Introduction of Programmable Logic Controller (PLC)

Programmable logic controllers are now the most widely used industrial process control technology. A programmable logic controller (PLC) is an industrial grade computer that is capable of being programmed to perform control functions. The programmable controller has eliminated much of the hardwiring associated with conventional relay control circuits. Other benefits include easy programming and installation, high control speed, network compatibility, troubleshooting and testing convenience, and high reliability. The programmable logic controller is designed for multiple input and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs for the control and operation of manufacturing process equipment and machinery are typically stored in battery-backed or non-volatile memory. A PLC is an example of a real-time system since the output of the system controlled by the PLC depends on the input conditions. The programmable logic controller is, then, basically a digital computer designed for use in machine control. Unlike a personal computer, it has been designed to operate in the industrial environment and is equipped with special input/output interfaces and a control programming language. The common abbreviation used in industry for these devices, PC, can be confusing because it is also the abbreviation for “personal computer.” Therefore, most manufacturers refer to their programmable controller as a PLC, which stands for “programmable logic controller.”

Advantages of PLC

Programmable controllers offer several advantages over a conventional relay type of control. Relays have to be hardwired to perform a specific function. When the system requirements change, the relay wiring has to be changed or modified. In extreme cases, such as in the auto industry, complete control panels had to be replaced since it was not economically feasible to rewire the old panels with each model changeover. The programmable controller has eliminated much of the hardwiring associated with conventional relay control circuits. It is small and inexpensive compared to equivalent relay-based process control systems. Modern control systems still include relays, but these are rarely used for logic. In addition to cost savings, PLCs provide many other benefits including:

- *Increased Reliability.* Once a program has been written and tested, it can be easily downloaded to other PLCs. Since all the logic is contained in the PLC's memory, there is no chance of making a logic wiring error. The program takes the place of much of the external wiring that would normally be required for

control of a process. Hardwiring, though still required to connect field devices, is less intensive. PLCs also offer the reliability associated with solid-state components.

- *More Flexibility.* It is easier to create and change a program in a PLC than to wire and rewire a circuit. With a PLC the relationships between the inputs and outputs are determined by the user program instead of the manner in which they are interconnected. Original equipment manufacturers can provide system updates by simply sending out a new program. End users can modify the program in the field, or if desired, security can be provided by hardware features such as key locks and by software passwords.
- *Lower Cost.* PLCs were originally designed to replace relay control logic, and the cost savings have been so significant that relay control is becoming obsolete except for power applications. Generally, if an application has more than about a half-dozen control relays, it will probably be less expensive to install a PLC.
- *Communications Capability.* A PLC can communicate with other controllers or computer equipment to perform such functions as supervisory control, data gathering, monitoring devices and process parameters, and download and upload of programs.
- *Faster Response Time.* PLCs are designed for highspeed and real-time applications. The programmable controller operates in real time, which means that an event taking place in the field will result in the execution of an operation or output. Machines that process thousands of items per second and objects that spend only a fraction of a second in front of a sensor require the PLC's quick-response capability.
- *Easier to Troubleshoot.* PLCs have resident diagnostics and override functions that allow users to easily trace and correct software and hardware problems. To find and fix problems, users can display the control program on a monitor and watch it in real time as it executes.

Different parts of PLC by drawing the block diagram and purpose of each part of PLC

A typical PLC can be divided into parts, as illustrated in Figure 1-8. These are the *central processing unit (CPU)*, the *input/output (I/O)* section, the *power supply*, and the *programming device*.

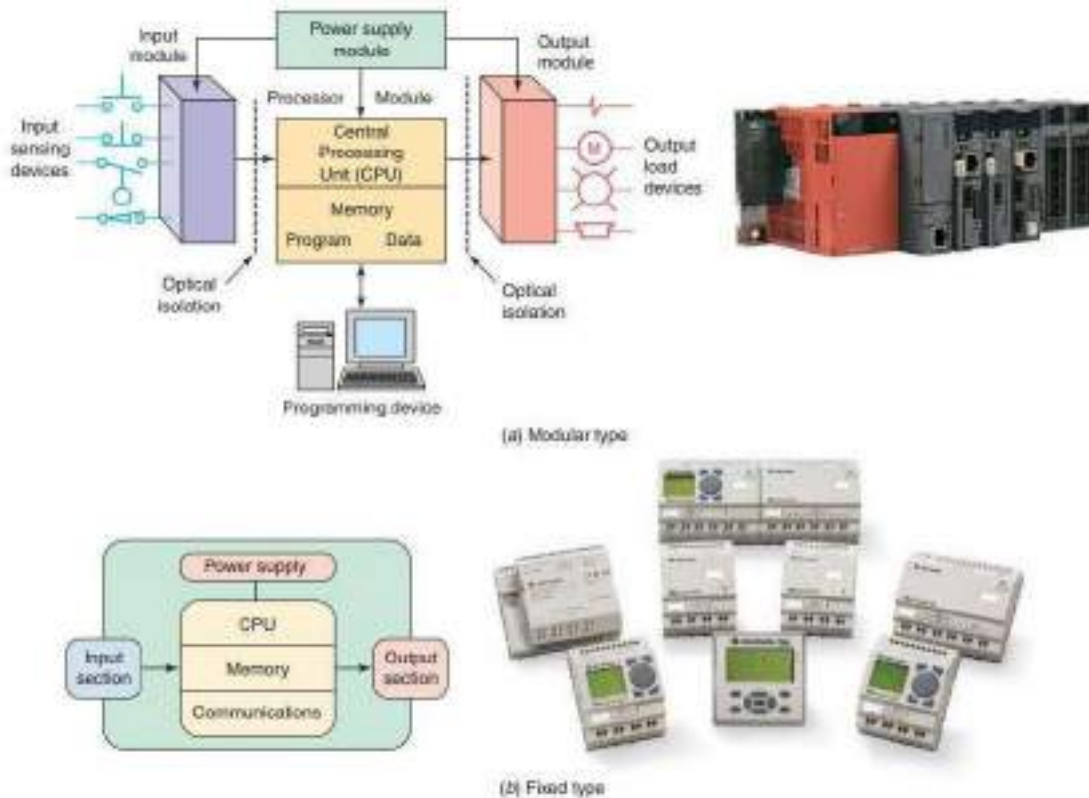


Figure 1-8 Typical parts of a programmable logic controller.
Source: (a) Courtesy Mitsubishi Automation; (b) Image Used with Permission of Rockwell Automation, Inc.

The term *architecture* can refer to PLC hardware, to PLC software, or to a combination of both. An *open* architecture design allows the system to be connected easily to devices and programs made by other manufacturers.

There are two ways in which I/Os (Inputs/Outputs) are incorporated into the PLC: fixed and modular. *Fixed I/O* is typical of small PLCs that come in one package with no separate, removable units. The processor and I/O are packaged together, and the I/O terminals will have a fixed number of connections built in for inputs and outputs. The main advantage of this type of packaging is lower cost. The number of available I/O points varies and usually can be expanded by buying additional units of fixed I/O. One disadvantage of fixed I/O is its lack of flexibility; you are limited in what you can get in the quantities and types dictated by the packaging. Also, for some models, if any part in the unit fails, the whole unit has to be replaced.

Modular I/O is divided by compartments into which separate modules can be plugged. This feature greatly increases your options and the unit's flexibility. You can choose from the modules available from the manufacturer and mix them any way you desire. The basic modular controller consists of a rack, power supply, processor module (CPU), input/output (I/O modules), and an operator interface for programming and monitoring. The modules plug into a rack. When a module is slid into the rack, it makes an electrical connection with a series of contacts called the backplane, located at the rear of the rack. The PLC processor is also connected to the backplane and can communicate with all the modules in the rack.

The *power supply* supplies DC power to other modules that plug into the rack. For large PLC systems, this power supply does not normally supply power to the field devices. With larger systems, power to field devices is provided by external alternating current (AC) or direct current (DC) supplies. For some small micro-PLC systems, the power supply may be used to power field devices.

The *processor* (CPU) is the "brain" of the PLC. A typical processor usually consists of a microprocessor for implementing the logic and controlling the communications among the modules. The processor requires memory for storing the results of the logical operations performed by the microprocessor. Memory is also required for the program EPROM or EEPROM plus RAM. The CPU controls all PLC activity and is designed so that the user can enter the desired program in relay ladder logic. The PLC program is executed as part of a repetitive process referred to as a scan. A typical PLC scan starts with the CPU reading the status of inputs. Then, the application program is executed. Once the program execution is completed, the CPU performs internal diagnostic and communication tasks. Next, the status of all outputs is updated. This process is repeated continuously as long as the PLC is in the run mode.

The *I/O system* forms the interface by which field devices are connected to the controller. The purpose of this interface is to condition the various signals received from or sent to external field devices. Input devices such as pushbuttons, limit switches, and sensors are hardwired to the input terminals. Output devices such as small motors, motor starters, solenoid valves, and indicator lights are hardwired to the output terminals. To electrically isolate the internal components from the input and output terminals, PLCs commonly employ an optical isolator, which uses light to couple the circuits together.

A *programming device* is used to enter the desired program into the memory of the processor. The program can be entered using relay ladder logic, which is one of the most popular programming languages. Instead of words, ladder logic programming language uses graphic symbols that show their intended outcome.

A program in ladder logic is similar to a schematic for a relay control circuit. It is a special language written to make it easy for people familiar with relay logic control to program the PLC.

A personal computer (PC) is the most commonly used programming device. Most brands of PLCs have software available so that a PC can be used as the programming device. This software allows users to create, edit, document, store, and troubleshoot ladder logic programs. The computer monitor is able to display more logic on the screen than can hand-held types, thus simplifying the interpretation of the program. The personal computer communicates with the PLC processor via a serial or parallel data communications link, or Ethernet. If the programming unit is not in use, it may be unplugged and removed. Removing the programming unit will not affect the operation of the user program.

A *program* is a user-developed series of instructions that directs the PLC to execute actions. A *programming language* provides rules for combining the instructions so that they produce the desired actions.

Relay ladder logic (RLL) is the standard programming language used with PLCs. Its origin is based on electromechanical relay control. The relay ladder logic program graphically represents rungs of contacts, coils, and special instruction blocks. RLL was originally designed for easy use and understanding for its users and has been modified to keep up with the increasing demands of industry's control needs.

Application of PLC

There are three major types of PLC application: single ended, multitask, and control management.

A *single ended* or stand-alone PLC application involves one PLC controlling one process. This would be a stand-alone unit and would not be used for communicating with other computers or PLCs. The size and sophistication of the process being controlled are obvious factors in determining which PLC to select. The applications could dictate a large processor, but usually this category requires a small PLC.

A *multitask* PLC application involves one PLC controlling several processes. Adequate I/O capacity is a significant factor in this type of installation. In addition, if the PLC would be a subsystem of a larger process and would have to communicate with a central PLC or computer, provisions for a data communications network are also required.

A *control management* PLC application involves one PLC controlling several others. This kind of application requires a large PLC processor designed to

communicate with other PLCs and possibly with a computer. The control management PLC supervises several PLCs by downloading programs that tell the other PLCs what has to be done. It must be capable of connection to all the PLCs so that by proper addressing it can communicate with anyone it wishes to

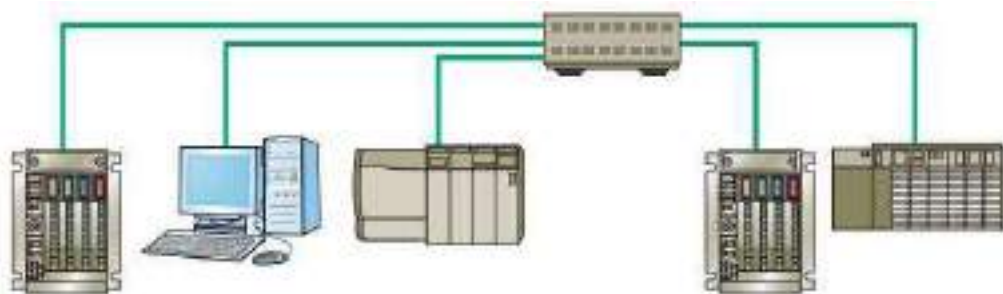


Figure 1-30 Control management PLC application.

Because of the versatility of PLC, it is used in various places for automation. In industries various processes needs to be controlled at every instant of time such as valve control, pressure control, robotic action, etc. It becomes tedious and infeasible for humans to control all such activities on their own. Thus, relays were used to perform those activities. However, a relay can be used only for a specific and limited operation which makes their use bulky and uneconomic. On the contrary PLC having the ability to perform number of tasks by simply modifying the program has become a prominent device for automation of such activities. There are various places where a PLC can be used. Some of those are listed as below:

- Robotic arm in car manufacturing
- Air compressors
- Airport runway lighting control
- Traffic signal control
- Smoke alarm control
- Process valve control
- Textile equipment
- Vacuum pump system

Apart from these applications, PLC is widely used in automation of electrical power system. At electrical substations automatic reclosing, circuit breaker tripping, capacitor switching, etc. can be controlled with PLCs.

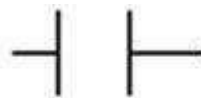
Ladder diagram

- Lets use a PLC in place of the relay.
- The first thing that's necessary is to create what's called a **Ladder Diagram**.
- We have to create one of these because, unfortunately, a PLC doesn't understand a schematic diagram it only recognizes code.
- Most PLCs have software which convert ladder diagrams into code.

- **First Step** : Translate all of the items we're using into symbols the PLC understands.
- **Second step** : We must tell the PLC where everything is located. In other words we have to give all the devices an address.
- **Final step** : We have to convert the schematic into a logical sequence of events.

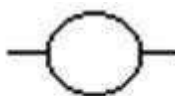
First step:

- The PLC doesn't understand terms like switch, relay, bell, etc.
- It prefers input, output, coil, contact, etc.
- It doesn't care what the actual input or output device actually is. It only cares that its an input or an output.
- First we replace the battery with a symbol. This symbol is common to all ladder diagrams. We draw what are called **bus bars**.
- These simply look like two vertical bars. One on each side of the diagram. Think of the left one as being + voltage and the right one as being ground. Further think of the current (logic) flow as being from left to right.
- Next we give the **inputs** a symbol. In this basic example we have one real world input. (i.e. the switch).
- We give the input that the switch will be connected to the symbol shown below. This symbol can also be used as the **contact of a relay**.



A contact symbol

- Next we give the **outputs** a symbol. In this example we use one output (i.e. the bell).
- We give the output that the bell will be physically connected to the symbol shown below. This symbol is used as the coil of a relay.



A coil symbol

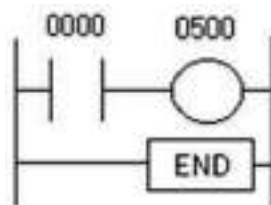
- The AC supply is an external supply so we don't put it in our ladder. The PLC only cares about which output it turns on and not what's physically connected to it.

Second step:

- We must tell the PLC where everything is located. In other words we have to give all the devices an address.
- Where is the switch going to be physically connected to the PLC? How about the bell? We start with a blank road map in the PLCs town and give each item an address.
- Could you find your friends if you didn't know their address? You know they live in the same town but which house? The plc town has a lot of houses (inputs and outputs) but we have to figure out who lives where (what device is connected where).
- We'll get further into the addressing scheme later. The PLC manufacturers each do it a different way! For now let's say that our input will be called "0000". The output will be called "500".

Final step:

- Convert the schematic into a logical sequence of events.
- The program we're going to write tells the PLC what to do when certain events take place.
- In our example we have to tell the plc what to do when the operator turns on the switch.



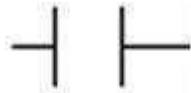
- Final converted diagram.
- We eliminated the real world relay from needing a symbol.

Description of contacts and coils in the following states

i) Normally open

Load :

- The load(LD) instruction is a **normally open contact**. It is sometimes also called examine if on (**XIO**).(as in examine the input to see if its physically on). The symbol for a load instruction is shown below.



A Load (contact) symbol

- This is used when an input signal is needed to be present for the symbol to turn on.
- When the physical input is on we can say that the instruction is True.
- We examine the input for an on signal. If the input is physically on then the symbol is on.
- An on condition is also referred to as a logic 1 state.

ii) Normally closed

Load Bar :

- The Load bar instruction is a **normally closed contact**. It is sometimes also called LoadNot or examine if closed (**XIC**) (as in examine the input to see if its physically closed) The symbol for a loadbar instruction is shown below.



A LoadNot (normally closed contact) symbol

- This is used when an input signal does not need to be present for the symbol to turn on.
- When the **physical input is off** we can say that the **instruction is True**.
- We examine the input for an off signal. If the input is physically off then the symbol is on.
- With most PLCs this instruction (**Load** or **Loadbar**) **MUST** be the first symbol on the left of the ladder.

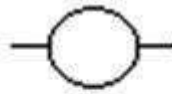
<u>Physical State</u>	<u>Instruction</u>	<u>Logic</u>
OFF	TRUE	0
ON	FALSE	1

iii) Energized output

out:

- The Out instruction is sometimes also called an **Output Energize instruction**. The output instruction is like a **relay coil**. Its symbol looks as shown below.
- When there is a path of True instructions preceding this on the ladder rung, it will also be True.

- When the **instruction is True it is physically ON.**
- We can think of this instruction as a normally open output.



An OUT (coil) symbol

Output energize (OTE)

- Alternate name: coil
- This instruction is usually used in conjunction with **XIC** or **XIO** or any other input instruction.
- If the logic preceding the OTE instruction is true (1), the OTE instruction will be energized

Instruction symbol

An OTE instruction can only be the last instruction on a rung.

Not energized

Energized

iv) Latched output

Output latch (OTL)

- The OTL instruction is used only to turn a bit on and latch it on

Instruction symbol

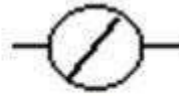
Initially not energized

Energized

Latched

Out bar:

- The Outbar instruction is sometimes also called an OutNot instruction.
- The Outbar instruction is like a **normally closed relay coil**. Its symbol looks like that shown below.



An OUTBar (normally closed coil) symbol

Ladder diagrams

i)AND gate

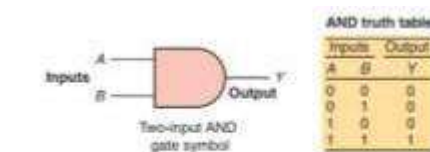


Figure 4-3 AND gate.

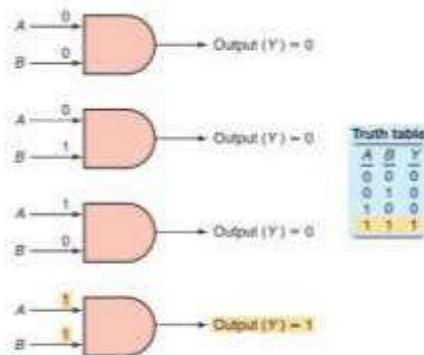


Figure 4-4 AND logic gate digital signal states.

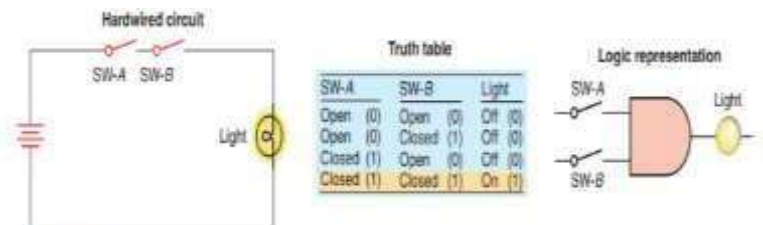
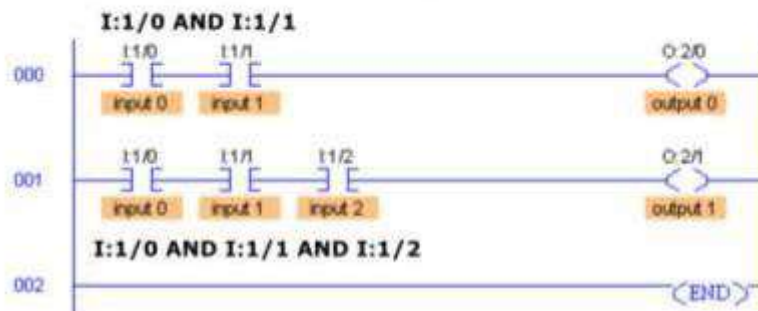


Figure 4-5 AND logic gate operates similarly to control devices connected in series.

Logical AND ladder diagram

- The logical AND function is constructed by series combinations of digital (discrete) inputs
 - Two (or more) series components



ii) OR gate

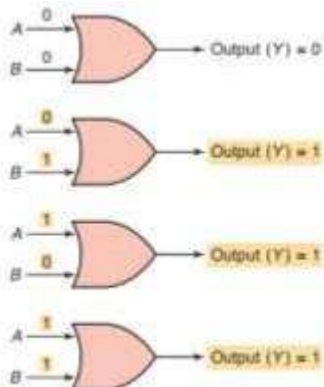


Figure 4-7 OR logic gate digital signal states.

Truth table		
Inputs		Output
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

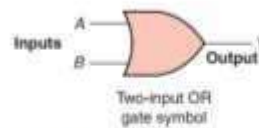
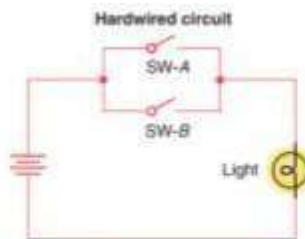


Figure 4-8 OR gate.

OR truth table		
Inputs		Output
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1



Truth table		
SW-A	SW-B	Light
Open (0)	Open (0)	Off (0)
Open (0)	Closed (1)	On (1)
Closed (1)	Open (0)	On (1)
Closed (1)	Closed (1)	On (1)

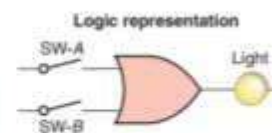
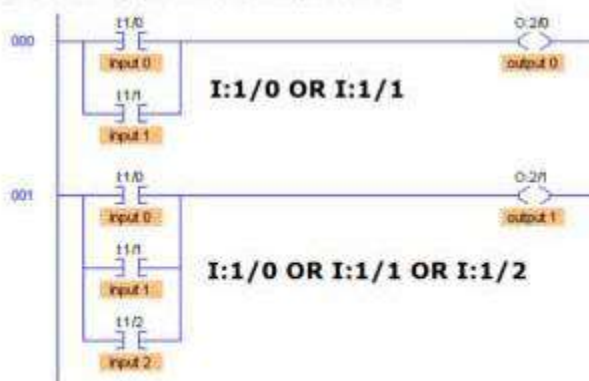


Figure 4-8 OR logic gate operates similarly to control devices connected in parallel.

Logical OR ladder diagram

- The logical OR function is constructed by parallel combinations of digital (discrete) inputs
 - Two (or more) parallel components



iii) NOT gate

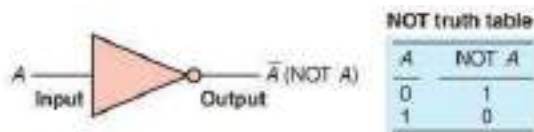


Figure 4-9 NOT function.

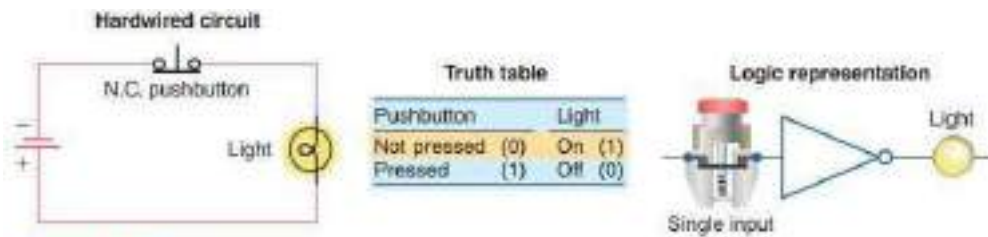
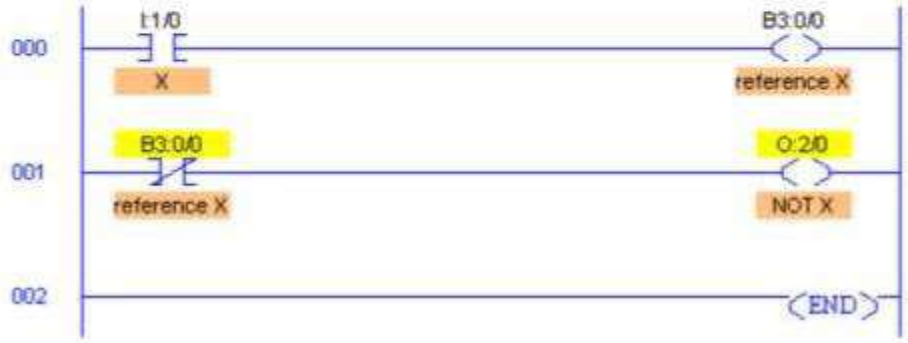


Figure 4-10 NOT function constructed using a normally closed pushbutton.

Logical NOT

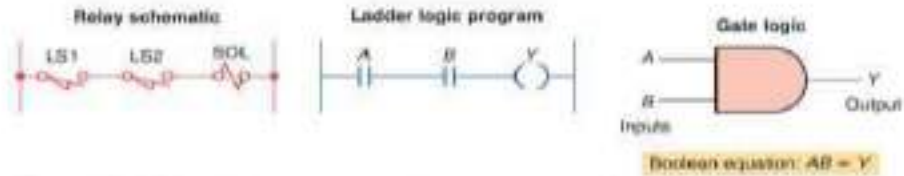
- The logical NOT function is constructed by referencing the input signal with a normally closed contact (XIO instruction)



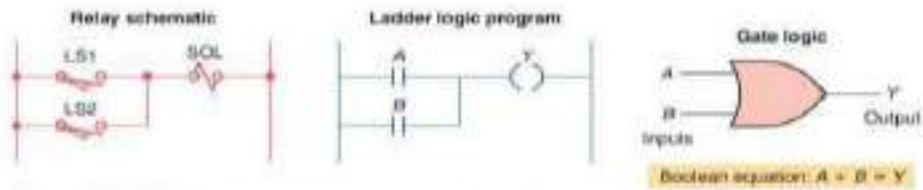
Ladder diagrams for combination circuits using NAND, NOR, OR and NOT

Table 4-1 Typical Boolean Instruction or Statement List

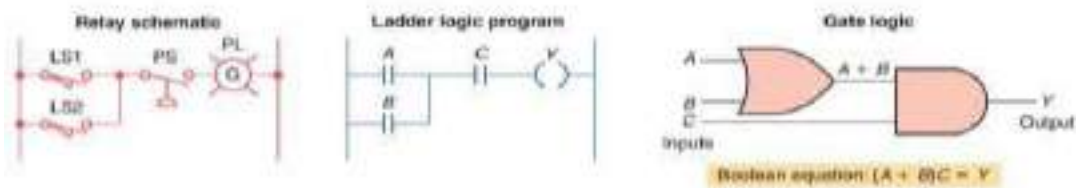
Boolean Instruction and Function	Graphic Symbol
Store (STR)–Load (LD) Begins a new rung or an additional branch in a rung with a normally open contact.	
Store Not (STR NOT)–Load Not (LD NOT) Begins a new rung or an additional branch in a rung with a normally closed contact.	
Or (OR) Logically ORs a normally open contact in parallel with another contact in a rung.	
Or Not (OR NOT) Logically ORs a normally closed contact in parallel with another contact in a rung.	
And (AND) Logically ANDs a normally open contact in series with another contact in a rung.	
And Not (AND NOT) Logically ANDs a normally closed contact in series with another contact in a rung.	
And Store (AND STR)–And Load (AND LD) Logically ANDs two branches of a rung in series.	
Or Store (OR STR)–Or Load (OR LOAD) Logically ORs two branches of a rung in parallel.	
Out (OUT) Reflects the status of the rung (on/off) and outputs the discrete (ON/OFF) state to the specified image register point or memory location.	
Or Out (OR OUT) Reflects the status of the rung and outputs the discrete (ON/OFF) state to the image register. Multiple OR OUT instructions referencing the same discrete point can be used in the program.	
Output Not (OUT NOT) Reflects the status of the rung and turns the output OFF for an ON execution condition; turns the output ON for an OFF execution condition.	



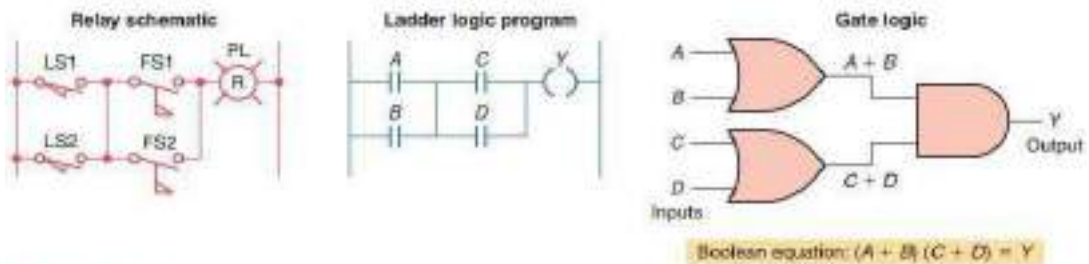
Example 4-1 Two limit switches connected in series and used to control a solenoid valve.



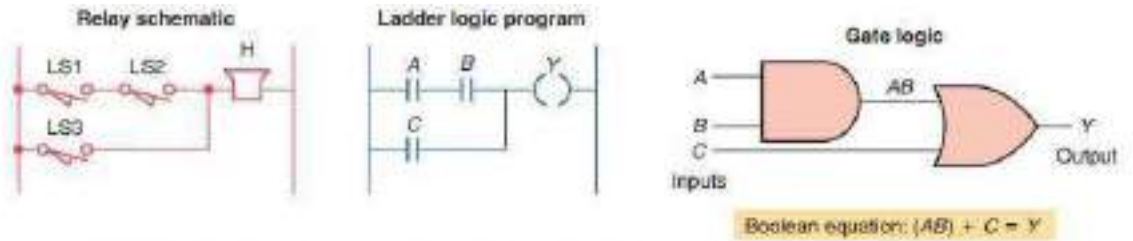
Example 4-2 Two limit switches connected in parallel and used to control a solenoid valve.



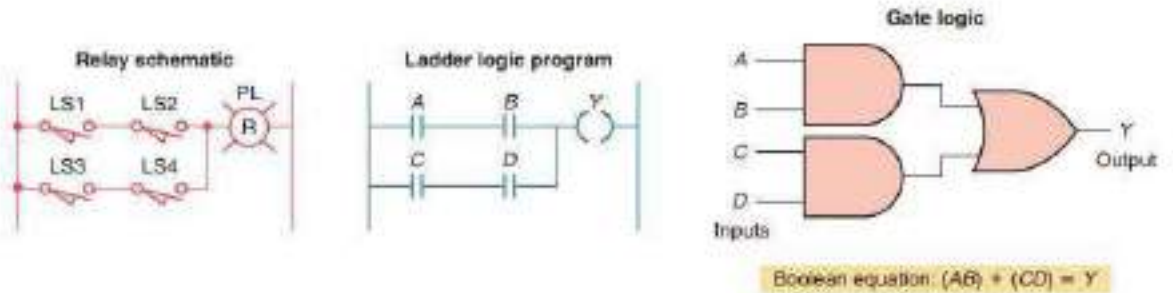
Example 4-3 Two limit switches connected in parallel with each other and in series with a pressure switch.



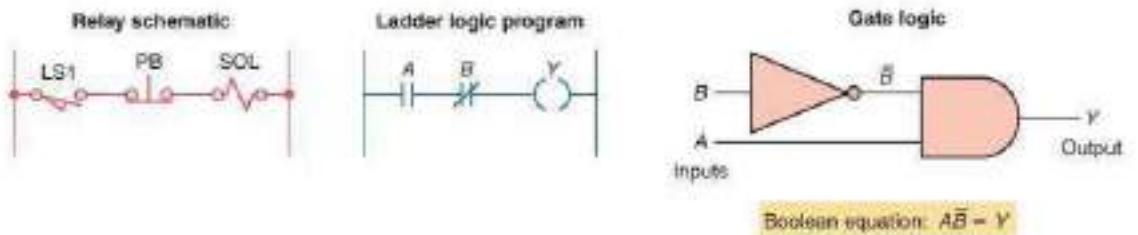
Example 4-4 Two limit switches connected in parallel with each other and in series with two sets of flow switches (that are connected in parallel with each other), and used to control a pilot light.



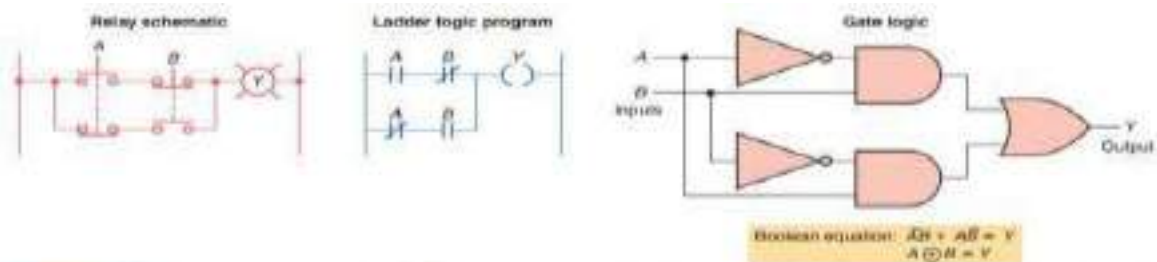
Example 4-5 Two limit switches connected in series with each other and in parallel with a third limit switch, and used to control a warning horn.



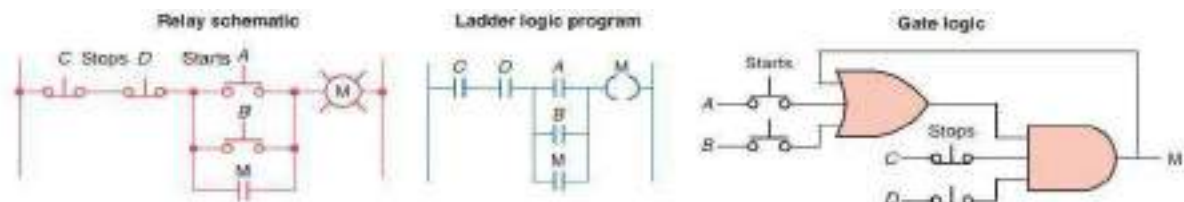
Example 4-6 Two limit switches connected in series with each other and in parallel with two other limit switches (that are connected in series with each other), and used to control a pilot light.



Example 4-7 One limit switch connected in series with a normally closed pushbutton and used to control a solenoid valve. This circuit is programmed so that the output solenoid will be turned on when the limit switch is closed and the pushbutton is *not* pushed.



Example 4-8 Exclusive-OR circuit. The output lamp of this circuit is ON only when pushbutton A or B is pressed, but not both. This circuit has been programmed using only the normally open A and B pushbutton contacts as the inputs to the program.



Example 4-9: A motor control circuit with two start/stop buttons: When either start button is depressed, the motor runs. By use of a seal-in contact, it continues to run when the start button is released. Either stop button stops the motor when it is depressed.

Timers)T ON

- **TIMER :** It is an instruction that waits a set amount of time before doing something.

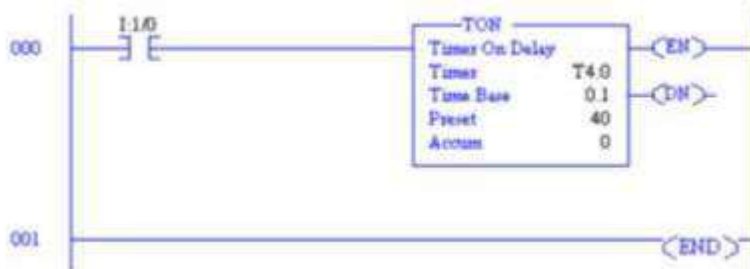
- Type of Timers : On-Delay Timer and Off-Delay Timer.

On-Delay Timer :

- Simply "delays turning on".
- After sensor (input) turns ON, wait x-seconds before activating a solenoid valve(output).
- This is the most common timer. It is often called **TON**(timer on-delay), **TIM**(timer) or **TMR**(timer).

Non-retentive Timers

- A single-input timer called a *non-retentive* timer is used in some PLCs.
 - Energizing I:1/0 causes the timer to run for 4 seconds.
 - At the end of 4 seconds the output (DN) goes on. When the input is de-energized, the output goes off and the timer resets to 0.
 - If the input I:1/0 is turned off during the timing interval (for example, after 2.7 seconds), the timer resets to 0.
 - **TON** is the basic non-retentive timer in Allen-Bradley PLCs



Timer Information

	/EN	/TT	/DN	PRE	ACC
T4.0	1	0	1	40	40
T4.1	0	0	0	0	0
T4.2	0	0	0	0	0
T4.3	0	0	0	0	0
T4.4	0	0	0	0	0

Radix: Decimal Table: T4 Timer
Address: Symbol:

- The timer table contains all information for that timer
 - /EN: Timer is enabled (i.e. the input rung is energized)
 - /TT: Timer is timing
 - /DN: Timer is done
 - .PRE: Timer preset value (point at which the timer stops timing)
 - .ACC: Timer accumulator (accumulated time value)

ii) T OFF

Off-Delay Timer :

- Simply "delays turning off".
- After sensor (input) sees a target it turn on a solenoid (output).
- When the sensor no longer sees the target it hold the solenoid on for x-seconds before turning it off.
- It is called a TOF (timer off-delay).

Timer Delay Off (TOF)

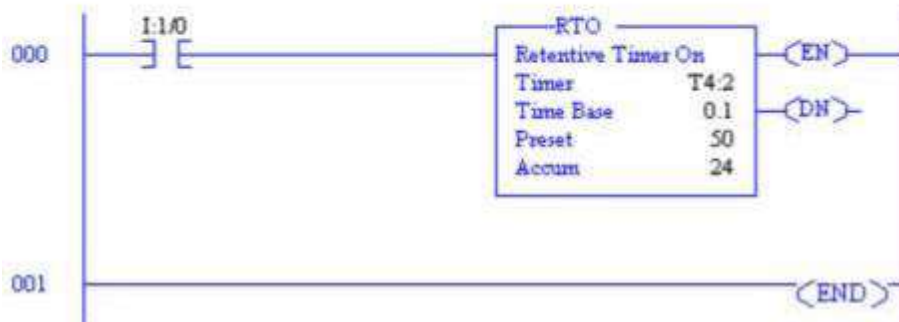
- The TOF timer functions the opposite of the TON timer.
 - De-Energizing I:1/0 causes the timer to run for 4.5 seconds. The DN bit is initially set.
 - At the end of 4.5 seconds the output (DN) goes off. When the input is energized the timer resets to 0.
 - If the input I:1/0 is turned on during the timing interval (for example, after 2.7 seconds), the timer resets to 0.



iii) Retentive timer

Retentive Timers (RTO)

- Functions exactly like TON except the accumulated time value is retained even if the input rung is de-energized.



CountersCTU

Up Counter (CTU)

- The CTU is an instruction that counts false-to-true rung transitions.
 - Rung transitions can be caused by events occurring in the program (from internal logic or by external devices) such as parts traveling past a detector or actuating a limit switch.
- When rung conditions for a CTU instruction have made a false-to-true transition, the accumulated value is incremented by one count, provided that the rung containing the CTU instruction is evaluated between these transitions.
 - The ability of the counter to detect false-to-true transitions depends on the speed (frequency) of the incoming signal.
- The accumulated value is retained when the rung conditions again become false.
- The accumulated count is retained until cleared by a reset (RES) instruction.

CTD

Down Counter (CTD)

- The CTD is an instruction that counts false-to-true rung transitions.
 - Rung transitions can be caused by events occurring in the program such as parts traveling past a detector or actuating a limit switch.
- When rung conditions for a CTD instruction have made a false-to-true transition, the accumulated value is decremented by one count, provided that the rung containing the CTD instruction is evaluated between these transitions.
- The accumulated counts are retained when the rung conditions again become false.
- The accumulated count is retained until cleared by a reset (RES) instruction.

Ladder diagram using Timers and Counters

Up Counter Example

- Accumulated count is reset only by the (RES) instruction
- The counter will increment the accumulator value even after the preset is reached

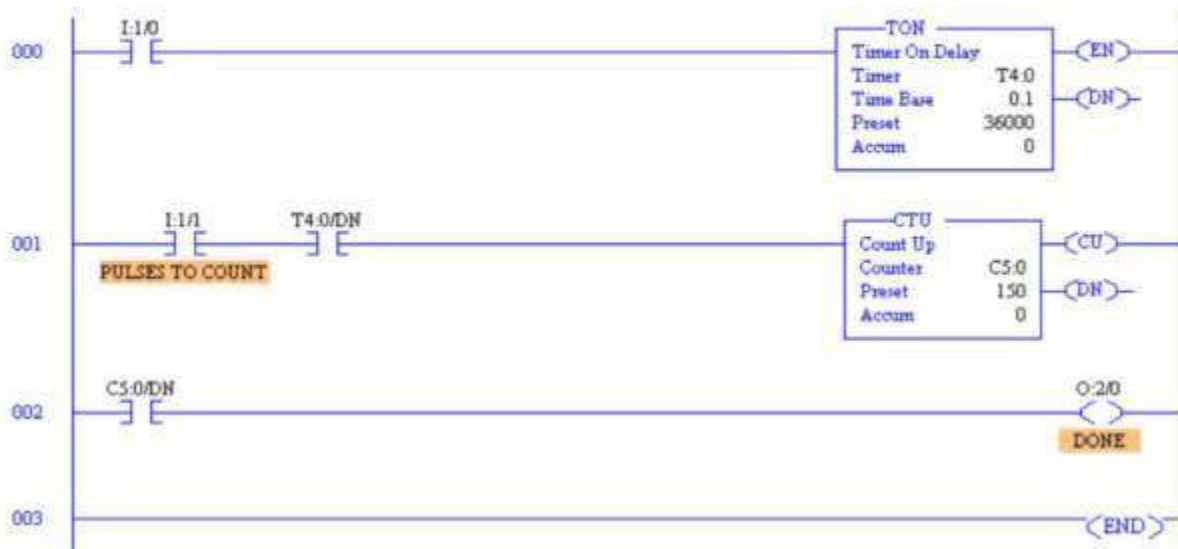


Down Counter Example

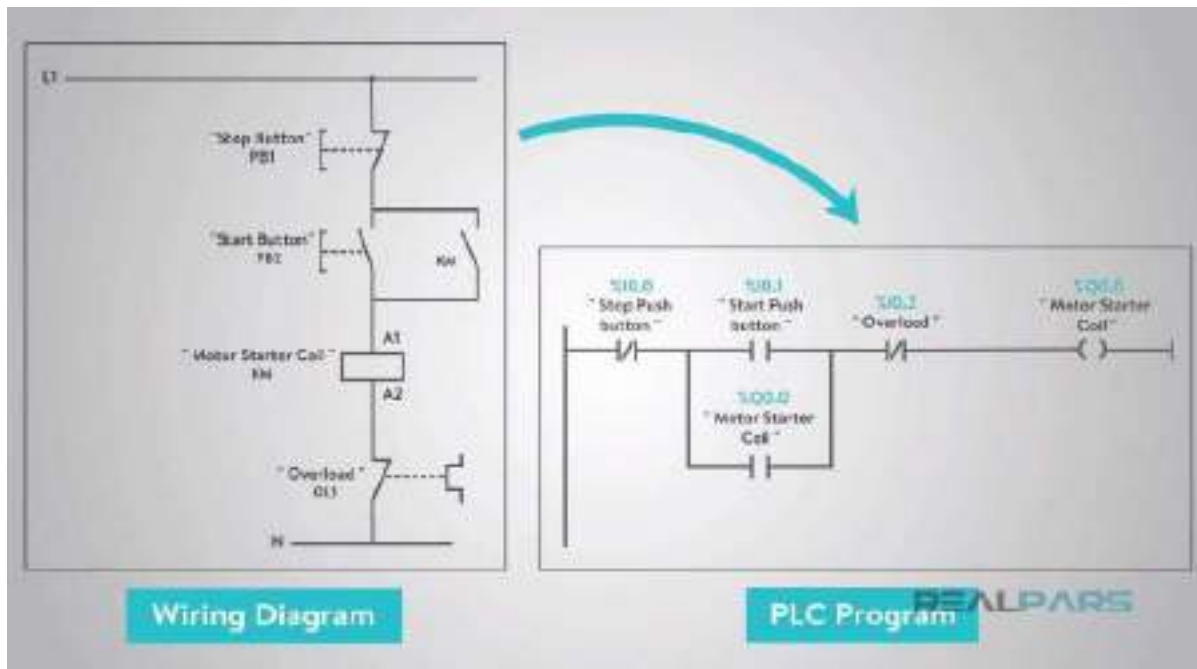
- Accumulated count is reset only by the (RES) instruction
- The counter will decrement the accumulator value even after a 0 count is reached



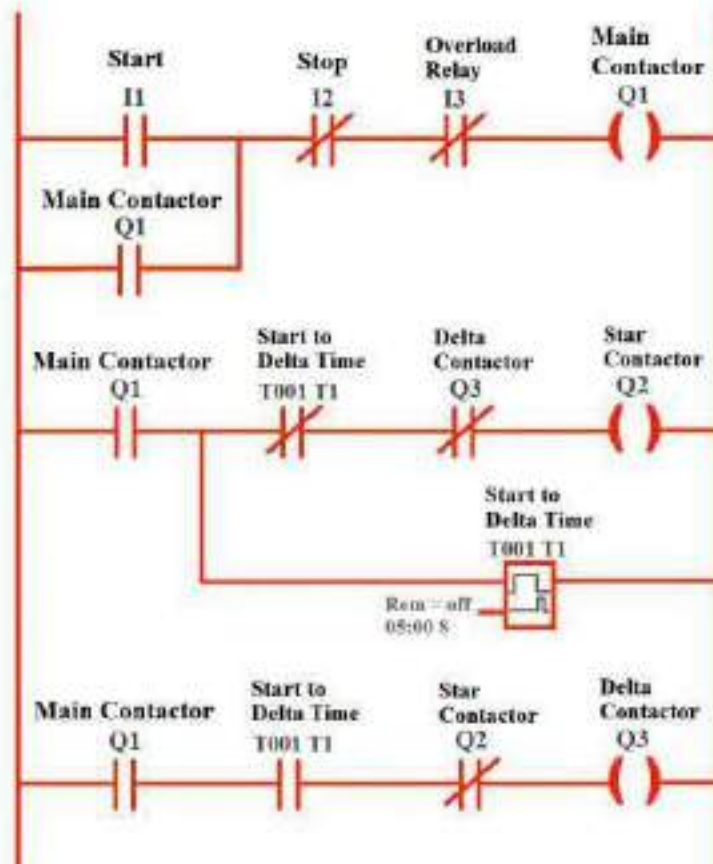
Ladder Logic Example



Ladder diagram for DOL starter



STAR-DELTA MOTOR STARTER LADDER LOGIC



SPECIAL CONTROL SYSTEMS

DCS:

A distributed control system (DCS) is part of a manufacturing system.

Distributed control systems (DCS) are used in industrial and civil engineering applications to monitor and control distributed equipment with remote human intervention.

It is generally, since the 1970s, digital, and normally consists of field instruments, connected via wiring to computer buses or electrical buses to multiplexer/demultiplexers and A/D's or analog to digital and finally the Human-Machine Interface (HMI) or control consoles. A DCS is a process control system that uses a network to interconnect sensors, controllers, operator terminals and actuators. A DCS typically contains one or more computers for control and mostly use both proprietary interconnections and protocols for communications. See PAS.

DCS is a very broad term that describes solutions across a large variety of industries, including:

- * Electrical power grids and electrical generation plants
- * Environmental control systems
- * Traffic signals
- * Water management systems
- * Refining and chemical plants
- * Pharmaceutical manufacturing

SCADA:

SCADA is the acronym for Supervisory Control And Data Acquisition. SCADA may be called Human-Machine Interface (HMI) in Europe. The term refers to a large-scale, distributed measurement (and control) system. SCADA systems are used to monitor or to control chemical, physical or transport processes.

The three components of a SCADA system are:

1. Multiple Remote Terminal Units (also known as RTUs or Outstations).
2. Master Station and HMI Computer(s).
3. Communication infrastructure

Contents

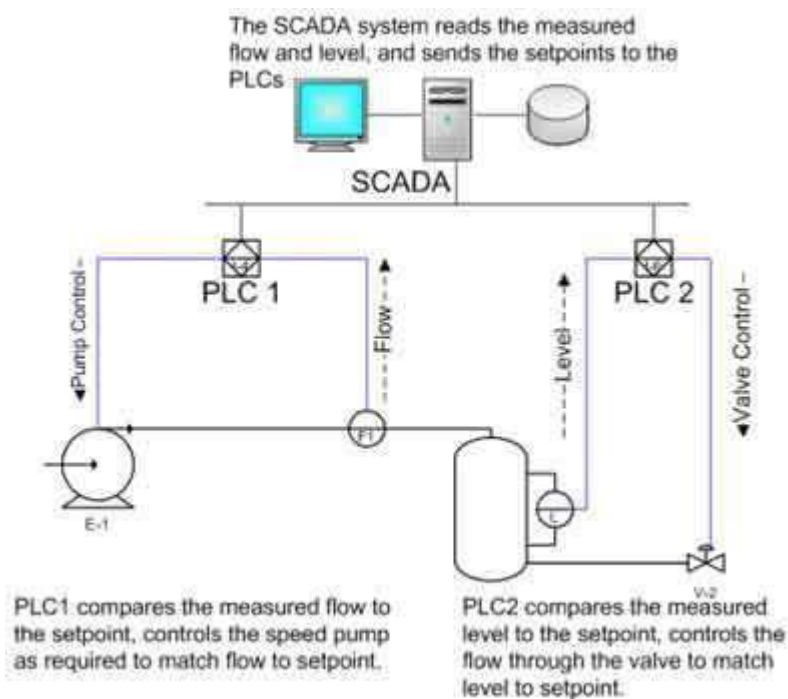
- * 1 Systems concepts
- * 2 Human Machine Interface
- * 3 Hardware solutions
- * 4 System components
- * 5 Remote Terminal Unit (RTU)
- * 6 Master Station
- * 7 Operational philosophy
- * 8 Communication infrastructure and methods
- * 9 Future trends in SCADA
- * 10 Practical uses
- * 11 External links

The term SCADA usually refers to a central system that monitors and controls a complete site. The bulk of the site control is actually performed automatically by a Remote Terminal Unit (RTU) or by a Programmable Logic Controller (PLC). Host control functions are almost always restricted to basic site over-ride or supervisory level capability.

SCADA systems typically implement a distributed database which contains data elements called points. A point represents a single input or output value monitored or controlled by the system. Points can be either "hard" or "soft". A hard point is representative of an actual input or output connected to the system, while a soft point represents the result of logic and math operations applied to other hard and soft points. The point values are normally stored as value-timestamp combinations; the value and the timestamp when the value was recorded or calculated. A series of value-timestamp combinations is the history of that point.

DCS vs. SCADA

DCS and SCADA are monitoring and control mechanisms that are used in industrial installations to keep track and control of the processes and equipment; to ensure that everything goes smoothly, and none of the equipment work outside the specified limits. The most significant difference between the two is their general design. DCS, or Data Control System, is process oriented, as it focuses more on the processes in each step of the operation. SCADA, or Supervisory Control and Data Acquisition, focuses more on the acquisition and collation of data for reference of the personnel who are charged with keeping track of the operation.



DCS is process state driven, while SCADA is event driven. DCS does all its tasks in a sequential manner, and events are not recorded until it is scanned by the station. In contrast, SCADA is event driven. It does not call scans on a regular basis, but waits for an event or for a change in value in one component to trigger certain actions. SCADA is a bit more advantageous in this aspect, as it lightens

the load of the host. Changes are also recorded much earlier, as an event is logged as soon as a value changes state.

In terms of applications, DCS is the system of choice for installations that are limited to a small locale, like a single factory or plant, while SCADA is preferred when the entire system is spread across a much larger geographic location, examples of which would be oil wells spread out in a large field. Part of the reason for this is the fact that DCS needs to be always connected to the I/O of the system, while SCADA is expected to perform even when field communications fail for some time. SCADA does this by keeping a record of all current values, so that even if the base station is unable to extract new information from a remote location, it would still be able to present the last recorded values.

Summary:

1. DCS is process oriented, while SCADA is data acquisition oriented.
2. DCS is process state driven, while SCADA is event driven.
3. DCS is commonly used to handle operations on a single locale, while SCADA is preferred for applications that are spread over a wide geographic location.