KARPAGAM COLLEGE OF ENGINEERING :: COIMBATORE

DEPARTMENT OF EEE

12E605 - POWER ELECTRONICS

CIA - (ii) ANSWER KEY.

PART - I

A1) SCR is not preferred for Inverters

The i/p of the inverter is DC source; hence natural commutation is not possible for the SCR's. Thus SCR's can be only turned off by means of forced commutation.

Also, the inverters often use PWM techniques. Hence switches need to be turned-on and off at high frequencies. The thyristors cannot be switched at such high PWM frequencies.

Hence, the SCR's are not preferred for inverters. (2m)

A2) Comparison between VSI and CSI

Voltage Source Inverter	Current Source Inverter
* I/p is constant voltage	* I/p is constant current
* Short circuit can damage the circuit	* Short circuit cannot damage the circuit
* Peak current of power device depends on load	* Peak current of power device is limited
* Current waveform depends on load	* Voltage waveform depends on load
* Freewheeling diodes are required in case of inductive load.	* Freewheeling diode are not required.

(2m)

A3) Condition to be satisfied in the selection of L and C in a series inverter

$$\boxed{R^2 < \frac{4L}{C}}$$

The series resonant RLC circuit must be underdamped.

(2m)

A4) Comparison between AC voltage controller and Cyclo converter.

AC voltage Controller	Cyclo converter.
It accepts fixed or variable ac input and gives regulated ac output without change in its frequency	In this, ac power at frequency is converted directly to a lower frequency in a single conversion stage.
The output voltage can be varied by varying the firing angle (or) by phase angle control.	Here, the output voltage and the output frequency can be varied by proper switching of the devices. (2m)

A5) Amplitude Modulation Index.

It is defined as the ratio of amplitude of reference signal to carrier signal

$M = \frac{Ar}{Ac}$

Ar → Amplitude of reference wave

Ac → Amplitude of carrier wave.

(2m)

A6. To operate the device within its upper temperature limit, the heat produced by losses in a device must be dissipated sufficiently & effectively.

Therefore, heat sink & cooling arrangement for devices are employed.

(2m)

A7. Thermal failure

It is a failure caused by inaccurate design of the heat sink or inadequate cooling arrangements.

Electrical failure.

A short circuit, which occurs when there is a junction breakdown because the device ratings are exceeded due to flaws in fabrication, results in electrical failure (2m)

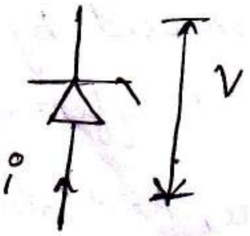
A8. Conditions for over current fault.

- ✓ Output Short circuit
- ✓ Internal faults in a thyristor circuit.
- ✓ Inversion failure in a forced-commutation circuits
- ✓ Short circuit between one of the phases of mains and the bridge.

(2m)

A9. Two types of Selenium Voltage limiter

a) Polarized →



b) Non-polarized,

↓

Circuit Symbols.

(2m)

A10. Necessity of heat sink.

Power dissipation in electrical components raises the internal temperature & affects performance and reliability.

A high internal temperature may be detrimental to the physical structure of the component.

Thus heat sink is necessary for the removal of heat & internal temperature of the electrical components.

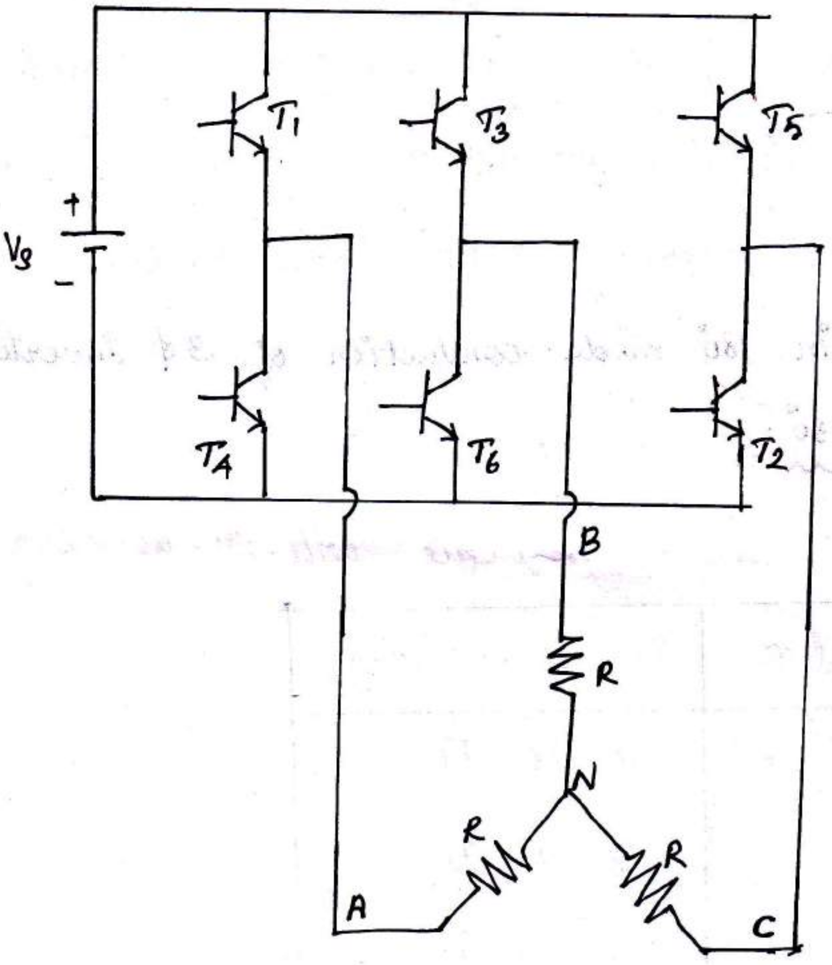
(2m)

Three phase Inverters

- For higher powers and 3ϕ Induction motor drives, 3ϕ inverters are used.

An inverter generates 3ϕ O/P A, B and C.

The load can be connected to the inverter in star or delta mode.



(1m)

The upper group devices are numbered as T_1, T_3 and T_5.

The lower group devices are numbered as T_4, T_6 and T_2

Here T_1 & T_4 are connected to phase A.

T_3 and T_6 " " " phase B

T_5 and T_2 " " " phase C.

Depending upon the drives applied to BJTs, there are 2 types of 3ϕ inverters, i) 180° conduction and ii) 120° conduction.

180° conduction type 3ϕ Inverter.

In this conduction mode, the base drive of T_1 is applied for 180° and it is off for remaining 180°.

Base drive of T_2 is applied with 60° delay w.r. to T_1.

Similarly, the base drives of other transistors are also delayed by 60° w.r. to previous one.

One cycle of 360° is divided into 6 intervals of 60° each.

These intervals are named as I, II, III, IV, V and VI.

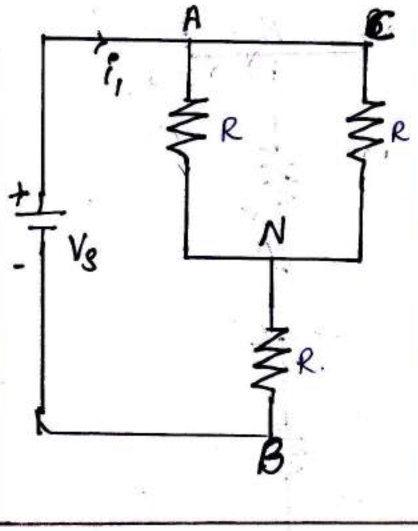
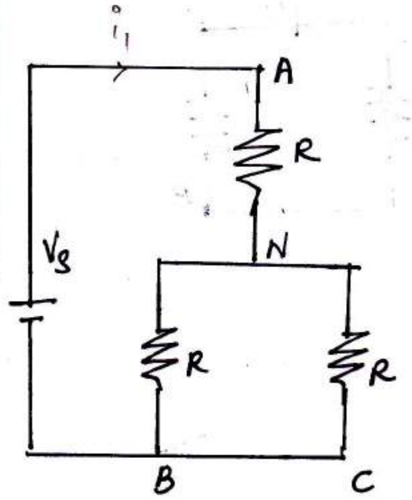
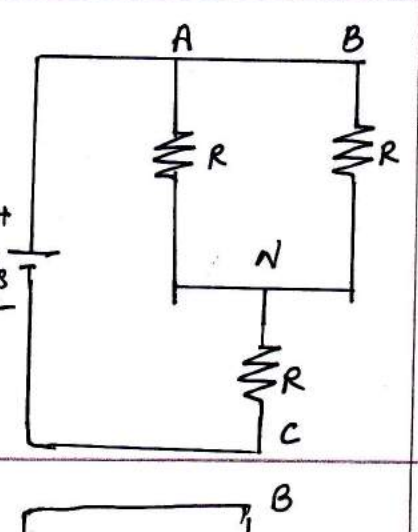
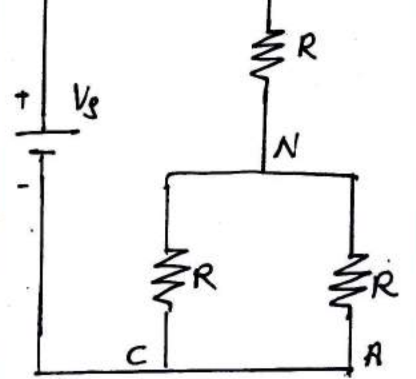
In each interval 3 transistors conduct.

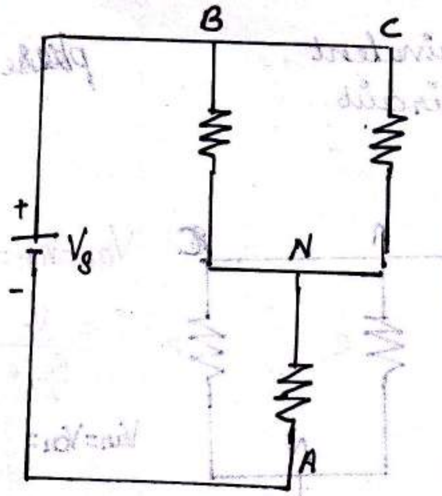
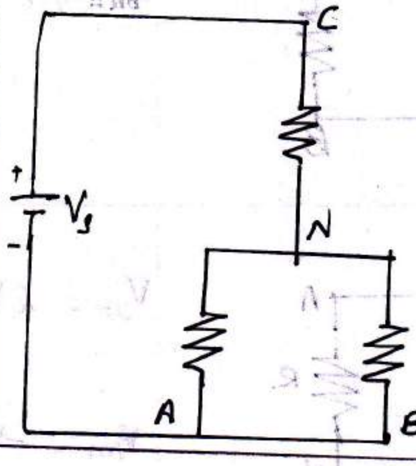
Thus in 180° mode conduction of 3ϕ Inverter each BJT conducts for 180°.

The conduction sequence will be as below:

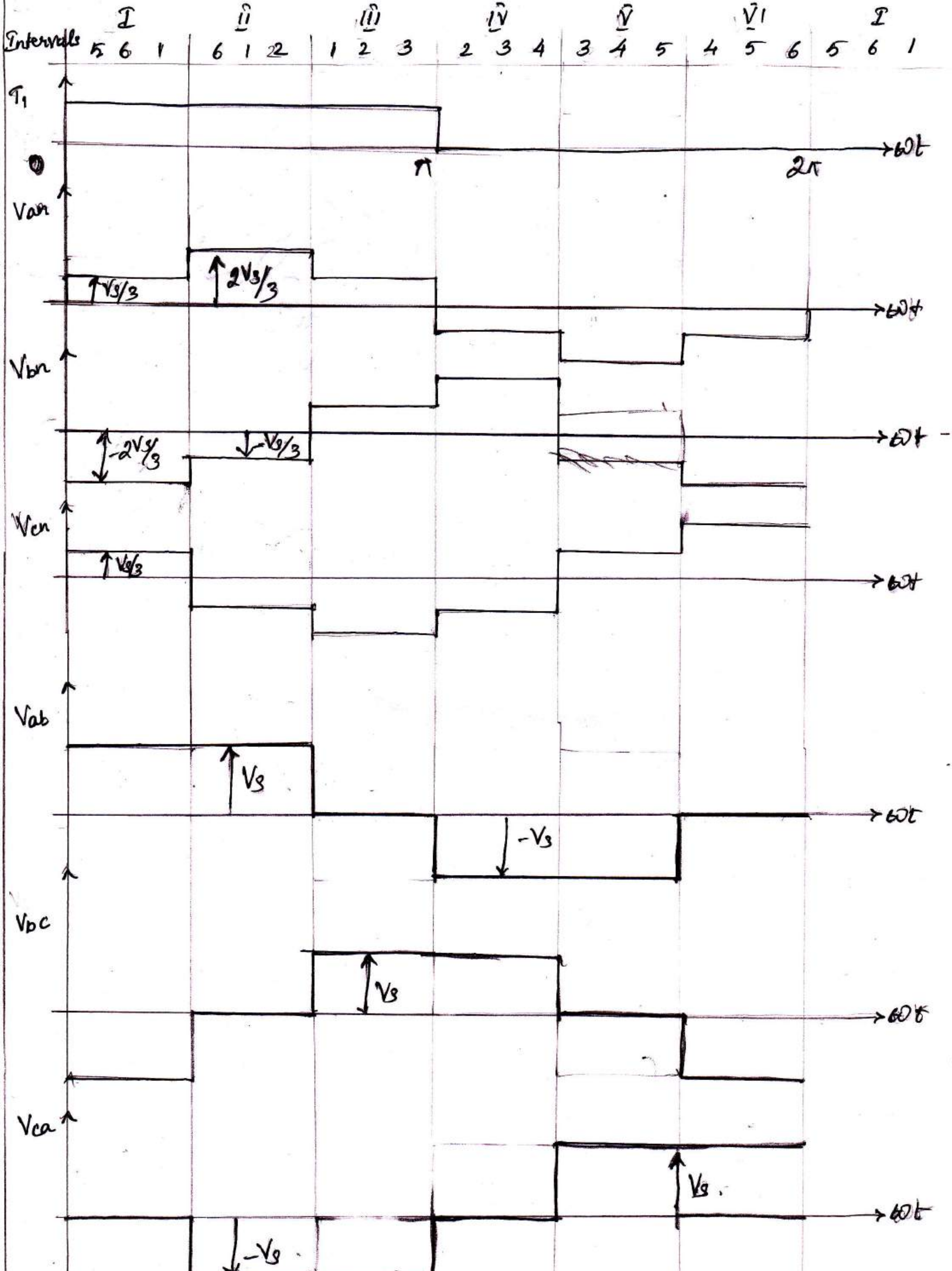
Interval	Devices conducting.
I	T_5 T_6 T_1
II	T_6 T_1 T_2
III	T_1 T_2 T_3
IV	T_2 T_3 T_4
V	T_3 T_4 T_5
VI	T_4 T_5 T_6.

(1m)

Interval	Conducting transistors	Equivalent circuit	phase voltage	line voltage.
i	T_5 T_6 T_1		$V_{an} = V_{cn} = i_1 \times \frac{R}{2}$ $i_1 = \frac{V_s}{\frac{R_2}{2}+R} = \frac{V_s}{3R/2} = \frac{2V_s}{3R}$ $V_{an} = V_{cn} = \frac{2V_s}{3R} \times \frac{R}{2} = \frac{V_s}{3}$ $V_{bn} = -i_1 \times R = \frac{-2V_s}{3R} \times R$ $= \frac{-2V_s}{3}$	$V_{ab} = V_{an} - V_{bn}$. $= \frac{V_s}{3} - \left(\frac{-2V_s}{3}\right)$ $\boxed{V_{ab} = V_s}$ $V_{bc} = V_{bn} - V_{cn}$ $= \frac{-2V_s}{3} - \frac{V_s}{3} = -V_s$ // $V_{ca} = V_{cn} - V_{an}$ $= \frac{V_s}{3} - \frac{V_s}{3} = 0$ //
ii	T_6 T_1 T_2		$V_{an} = 2V_s/3$. $V_{bn} = -V_s/3$. $V_{cn} = \frac{-V_s}{3}$	$V_{ab} = V_s$ $V_{bc} = 0$ $V_{ca} = -V_s$. $= -V_s$
iii	T_1 T_2 T_3		$V_{an} = V_s/3$ $V_{bn} = V_s/3$ $V_{cn} = \frac{-2V_s}{3}$	$V_{ab} = 0$ $V_{bc} = V_s$ $V_{ca} = -V_s$
iv	T_2 T_3 T_4		$V_{an} = -V_s/3$ $V_{bn} = 2V_s/3$ $V_{cn} = -V_s/3$	$V_{ab} = -V_s$ $V_{bc} = V_s$ $V_{ca} = 0$

V	T_3 T_4 T_5		$V_{an} = -2V_s/3$ $V_{bn} = -V_s/3$ $V_{cn} = +V_s/3$	$V_{ab} = -V_s$. $V_{bc} = 0$ $V_{ca} = V_s$.
VI	T_4 T_5 T_6		$V_{an} = -V_s/3$. $V_{bn} = -2V_s/3$ $V_{cn} = +2V_s/3$	$V_{ab} = 0$ $V_{bc} = -V_s$ $V_{ca} = V_s$.

(Am)


Intervals
I
II
III
IV
V
VI
I
5 6 1
6 1 2
1 2 3
2 3 4
3 4 5
4 5 6
5 6 1
T1
0
π
2π
ωt
Van
Vs/3
2Vs/3
ωt
Vbn
-2Vs/3
-Vs/3
ωt
Vcn
Vs/3
ωt
Vab
Vs
-Vs
ωt
Vbc
Vs
ωt
Vca
Vs.
-Vs
ωt

(2m)

⑤

B1) a)ii) Voltage control methods in inverters.

a) External control of ac output voltage

b) External control of dc input voltage

c) Internal control of inverter.

External control of ac output voltage.

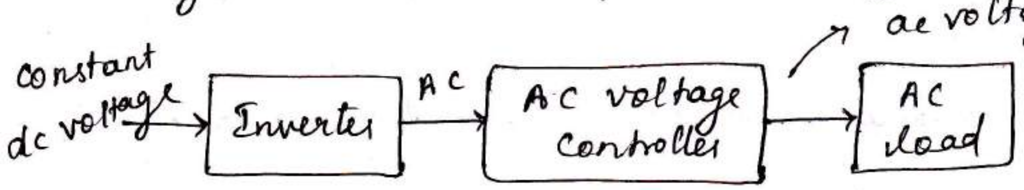
There are two possible methods of external control of ac o/p voltage obtained from inverter o/p terminals. These are

a) AC voltage control

b) Series - inverter control.

(1m)

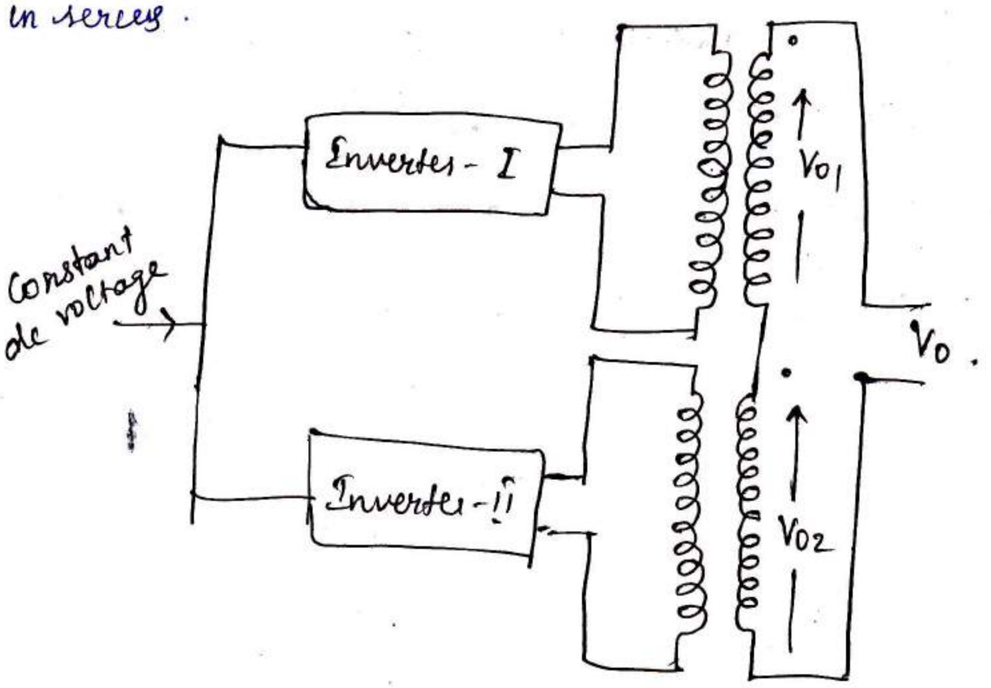
AC voltage control.

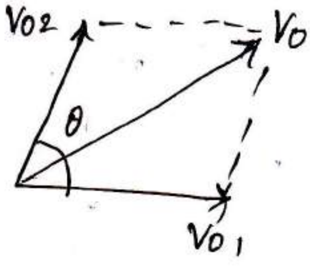


This method gives rise to more harmonics.

Series inverter control.

This method of control involves the use of 2 or more inverters in series.



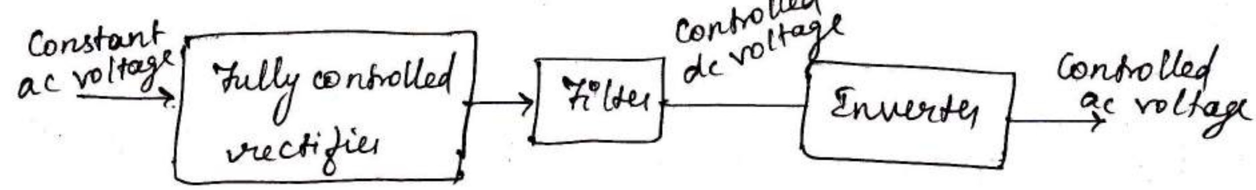


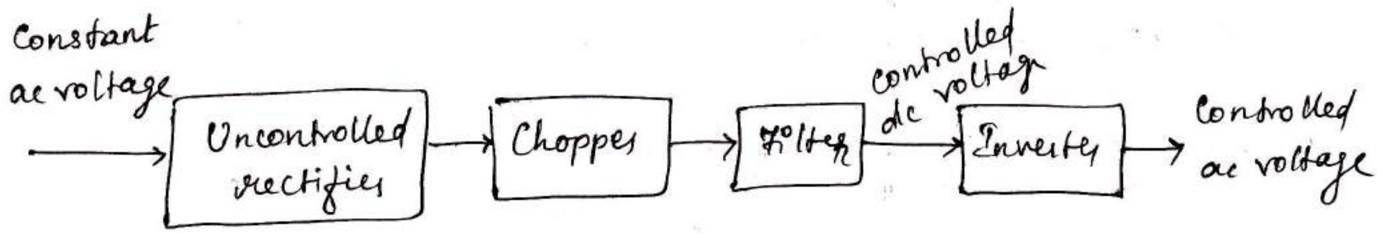
(1m)

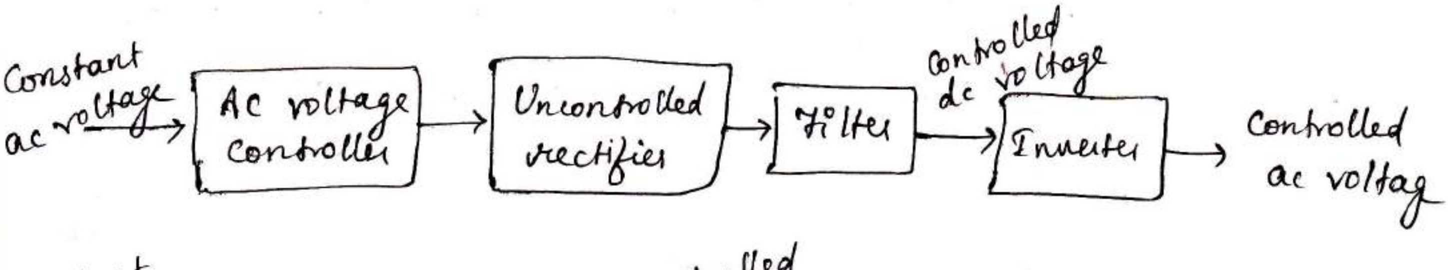
O/P voltage $V_o = \left[V_{o1}^2 + V_{o2}^2 + 2V_{o1}.V_{o2}\cos\theta\right]^{1/2}$

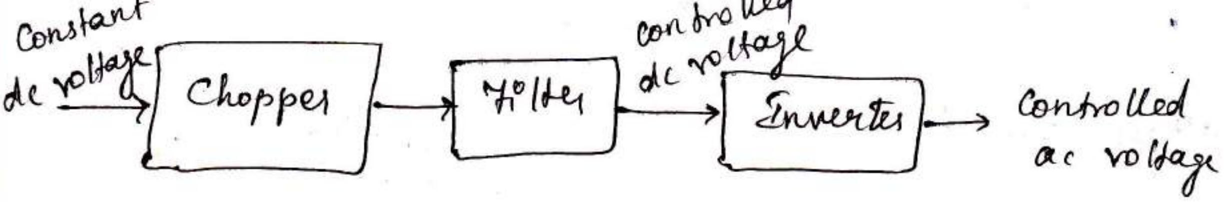
⑥

External control of dc i/p voltage.









In case the available voltage is ac, then dc voltage i/p to the inverter is controlled through a fully controlled rectifier (1m)

Internal Control of Inverter.

O/p voltage from an inverter can also be adjusted by exercising a control within the inverter itself.

The most efficient method of doing this is by pulse-width modulation control used within an inverter.

(1m)

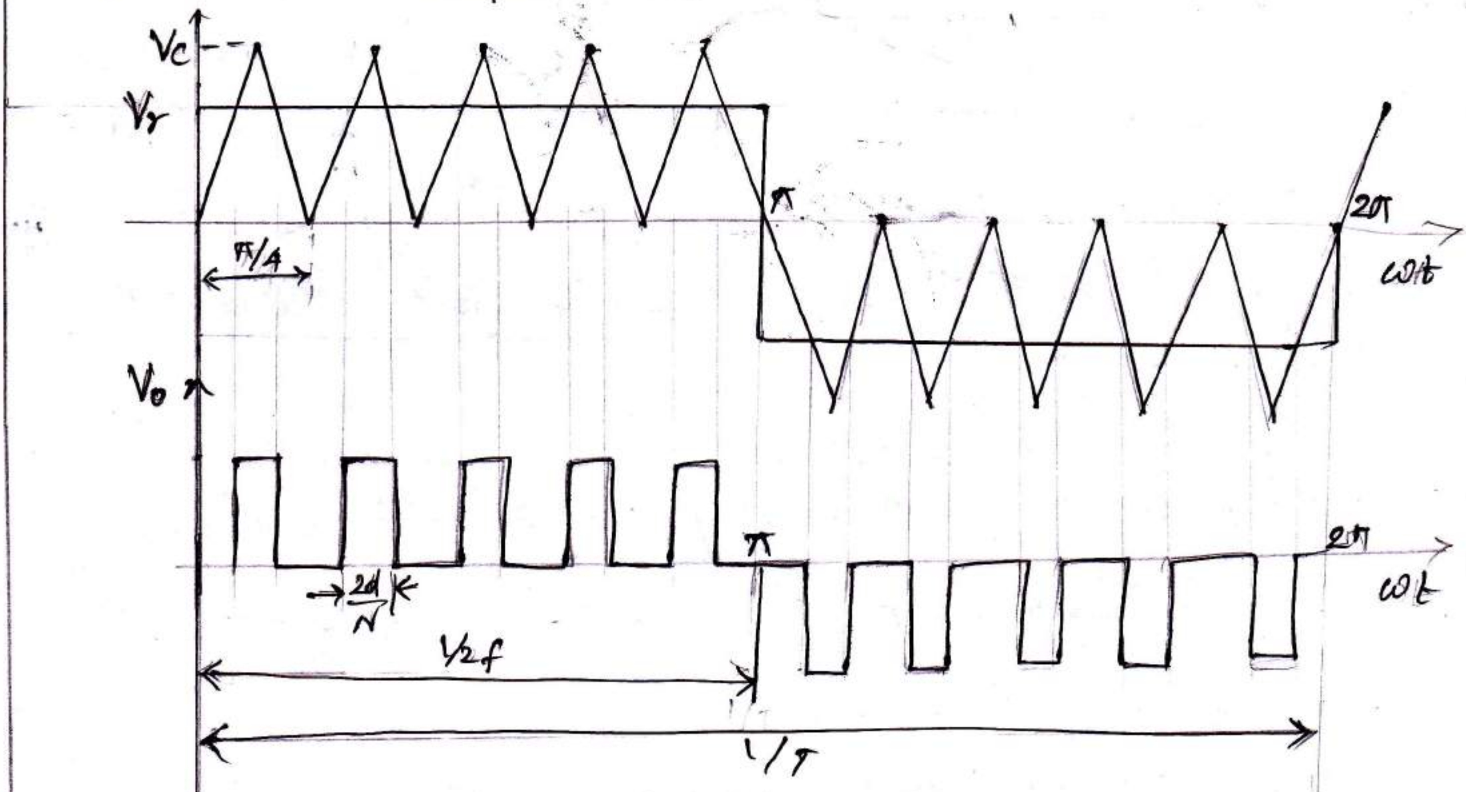
B1)
a)iii) Comparison between Multiple PWM with Sinusoidal PWM.

In Multiple Pulse Width Modulation, the pulse width is equal for all the pulses.

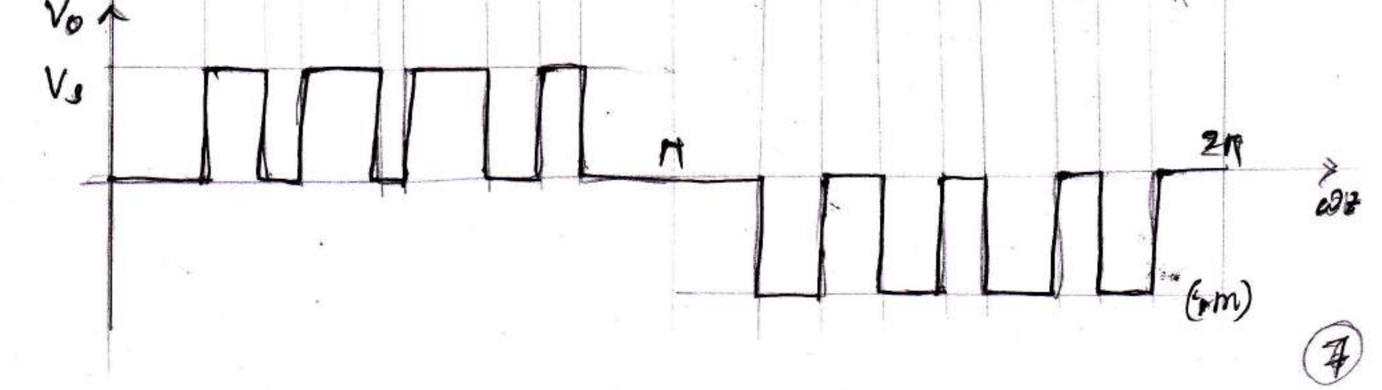
But in Sinusoidal Pulse Width Modulation, the pulse width is a sinusoidal function of the angular position of the pulse in a cycle.

Multiple PWM

(2m)

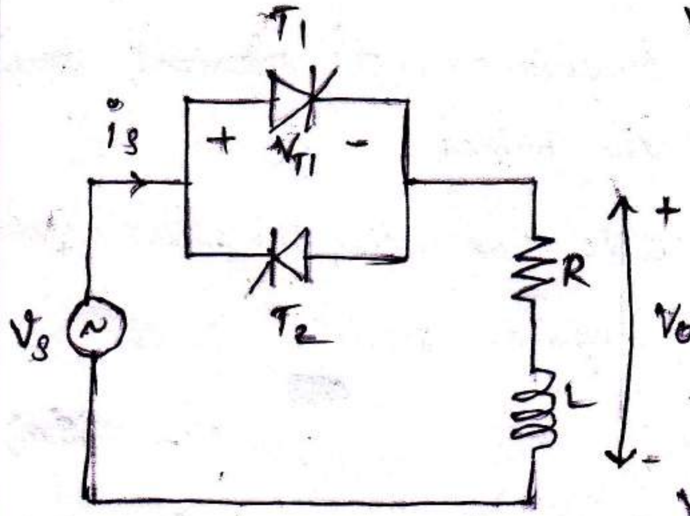


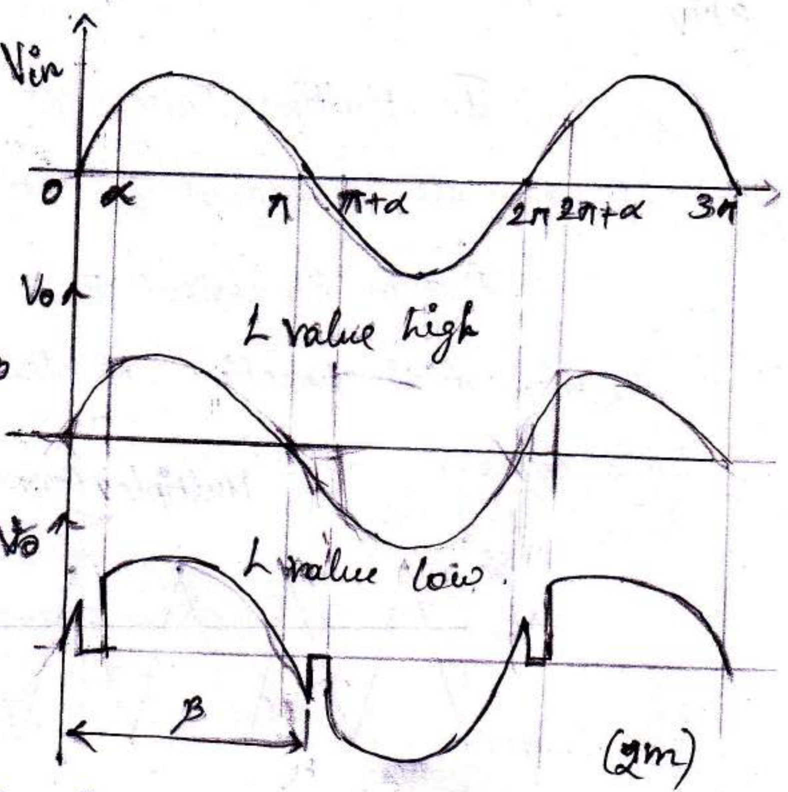
Sinusoidal PWM.



(4m)

B1) b) i) Single phase bidirectional AC voltage controller with RL Load





(1m)

(2m)

Mode 1: 0 to π

T_1 - Forward biased.

At $\omega t = \alpha$, T_1 is triggered & $i_0 = i_{T1}$ starts building up through the load.

At π, load and source voltages are zero but the current is not zero because of the presence of inductance in load circuit.

$V_s^{+} \rightarrow T_1 \rightarrow$ RL load $\rightarrow V_s$ $V_0 = +ve$

Mode 2: π to 2π

T_2 - Forward biased

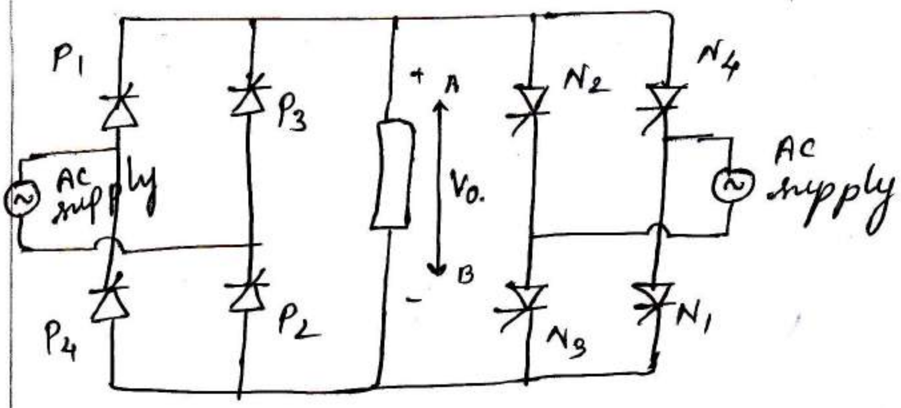
At $\omega t = \pi + \alpha$, T_2 is triggered & $i_0 = i_{T2}$ starts building in the reversed direction through the load.

$V_s \rightarrow RL \rightarrow T_2 \rightarrow V_s$ $V_0 = -ve$

(2m)

Step up bridge type Cycloconverter.

ii)



(1m)

Cycloconverters converts ac power at one frequency to a another frequency in a single conversion stage.

During +ve half cycle (0 to π)

P_1, P_2 → Forward biased. (So V_0 = +ve voltage is obtained)

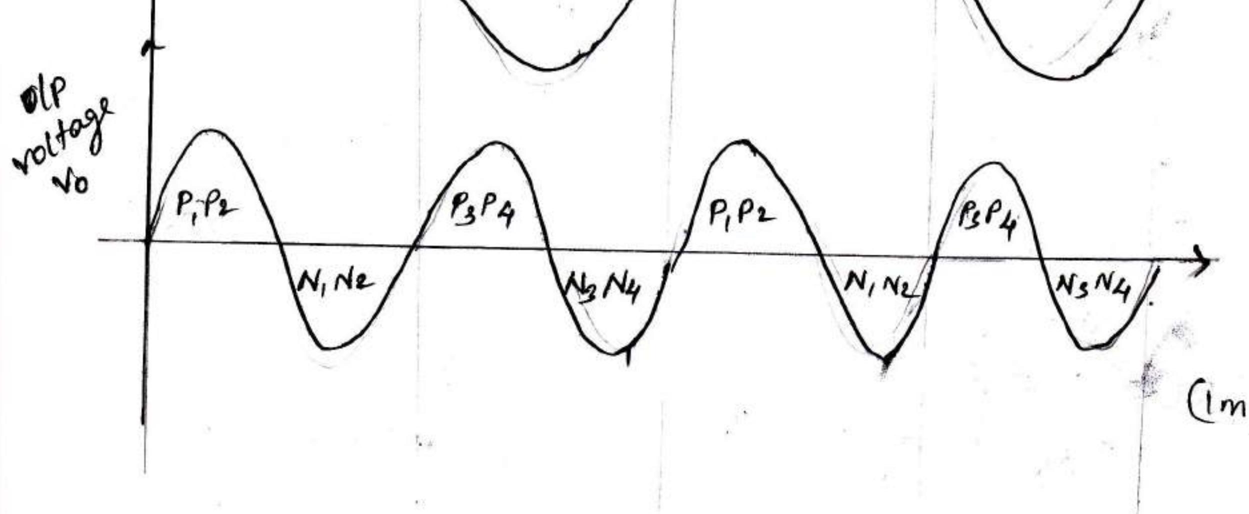
Also N_1, N_2 → Forward biased (So V_0 = -ve voltage is obtained)

During -ve half cycle,

$P_3\ P_4$ → Forward biased (V_0 - +ve)

$N_3\ N_4$ → Forward biased (V_0 - -ve).

(2m)



(1m)

B1) b) iii) **Effects of harmonics present in the inverter system**

i) Harmonic currents will lead to excessive heating in the induction motors connected with the thyristor system. This will reduce the load carrying capacity of the motor.

ii) If the control and regulating circuits are not properly shielde harmonics from power side can affect their operation & malfunctioning can result.

iii) On critical loads, torque pulsation produced by the harmonic current can be harmful.

iv) Harmonic currents cause losses in the a.c system and can even some-time produce resonance in the system.

(3m)

Methods to reduce harmonic content

i) Single-pulse width modulation

ii) Transformer connections

iii) Multiple commutations in each half-cycle

iv) Stepped wave-inverters

Normally, a single-phase bridge inverter produces a square wave. This square-waveform contains 33 1/3 percent third harmonic, 20% fifth harmonic & 14 1/2 % seventh harmonic.

In some applications, harmonics at the output should be less than 5%.

It is customary to reduce the lower order harmonics by some technique & use filter for higher order harmonics.

(2m)

2e) Overvoltage conditions.

a) i)

Devices can be damaged by excessive vol applied even for very short periods of time.

There are many such transient condns in all power electronic ckts & it is necessary to understand them to ensure satisfactory protection.

The conditions most important to power-electronic ckt's are:

(i) Lightning surges (ii) Transformer switching
(iii) Thyristor turn-off (iv) Load switching, etc.,

(1m)

Lightning Surges.

Lightning strikes on overhead power-lines can be passed through the supply n/w & appear on all power-electronic ckts which are directly connected to the n/w.

They are usually attenuated by supply system transformers & lightning arrestors but can still be many times the normal vol level lasting for periods up to tens of μsec.

Fortunately, their magnitude tends to reduce as the time of the transient is.

In some applications, the o/p connections from the thyristor ckt may be exposed to lightning.

eg: dc transmission & traction, & o/p vol suppression ckts will then be needed.

Transformer switching

It is a regular + significant source of transient overvoltages, particularly when a thyristor equipment is supplied by its own transformer.

Transients will occur on the secondary windings when its 1° cty is opened or closed.

These occur even when the equipment & transformer are unloaded due to the magnetizing condn's within the transformer.

When the supply is closed on to the transformer, the inrush magnetizing cty causes vol of upto twice the normal to occur transiently.

Capacitive coupling b/w the 1° & 2° can temporarily boost the 2° voltage if the transformer has a large step-down ratio. Refer fig a to c.

Power device turn-off

When any device turn-off at a relatively high rate of change of cty, a reverse cty will flow to sweep away the stored charge.

Once this has been achieved the cty quickly reduces to zero, inducing high voltages in the ckt inductances.

These vol can be extremely high if no protection is included to limit them; they appear as reverse voltage across the device which are turning off, & they are reflected onto other devices in the ckt in both polarities.

The stored charge & hence, the level of reverse 'charge recovery' C_q varies b/w thyristors & due to temperature, such max values have to be used in assessing protection requirements.

Voltage transient due to interruption of transformer magnetizing current

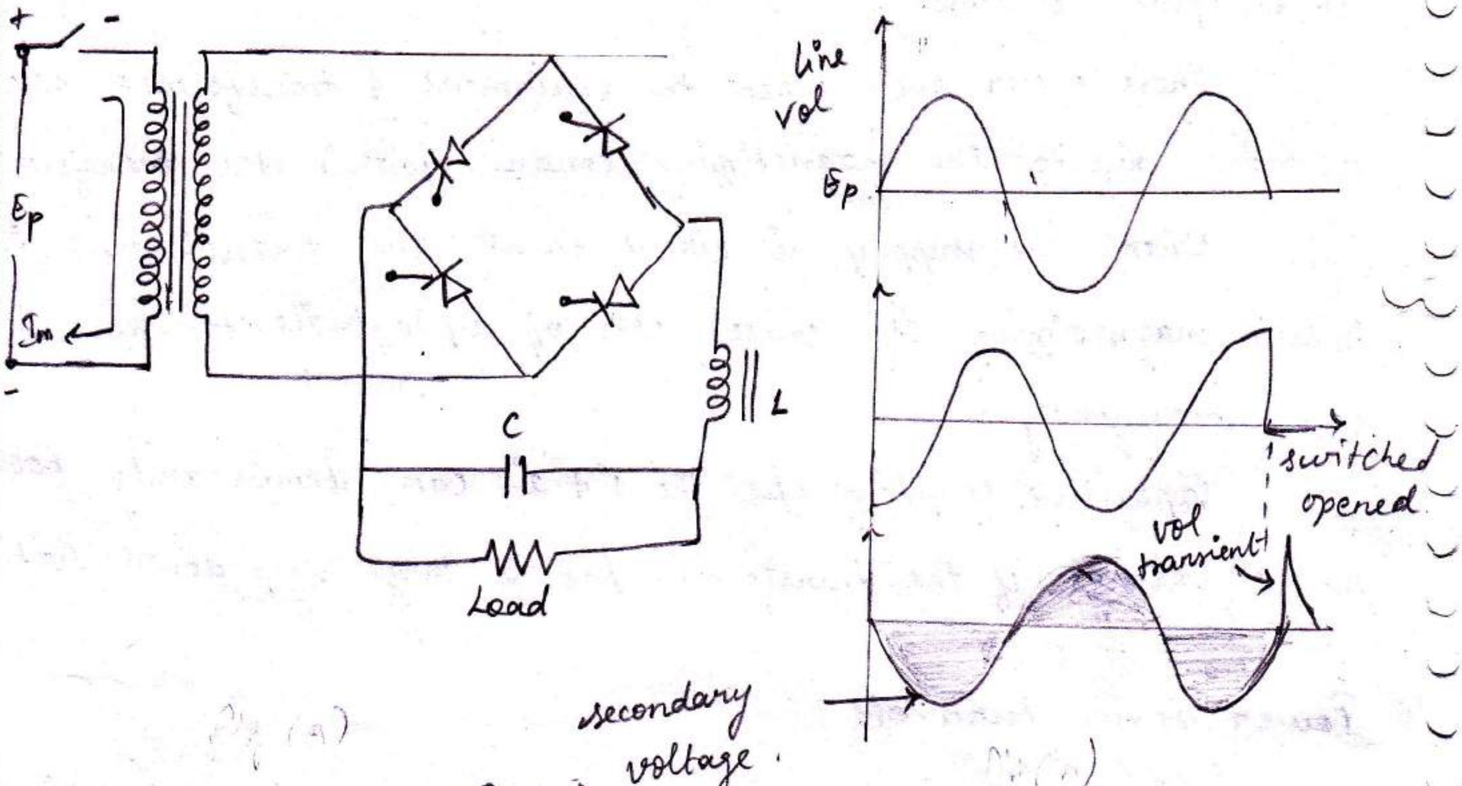


fig (a)

Voltage transient due to energizing transformer primary

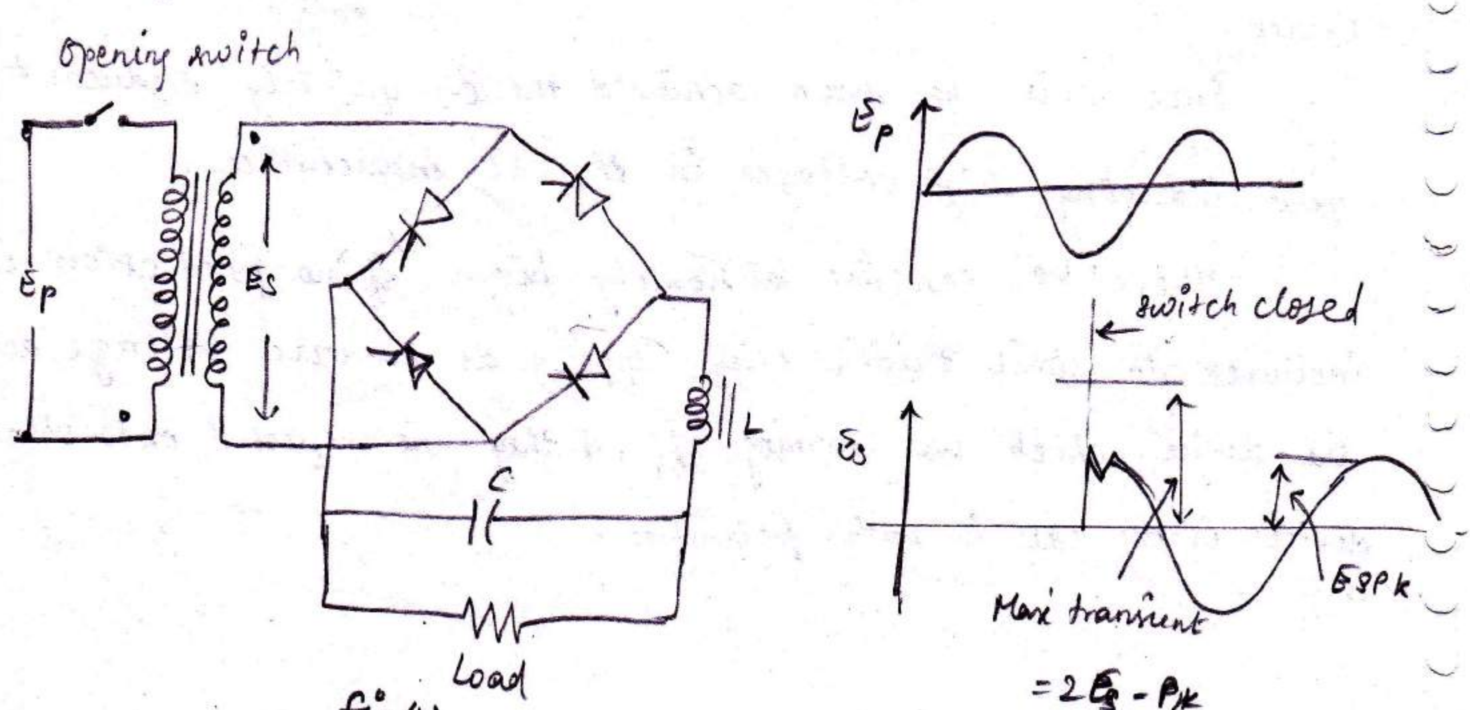
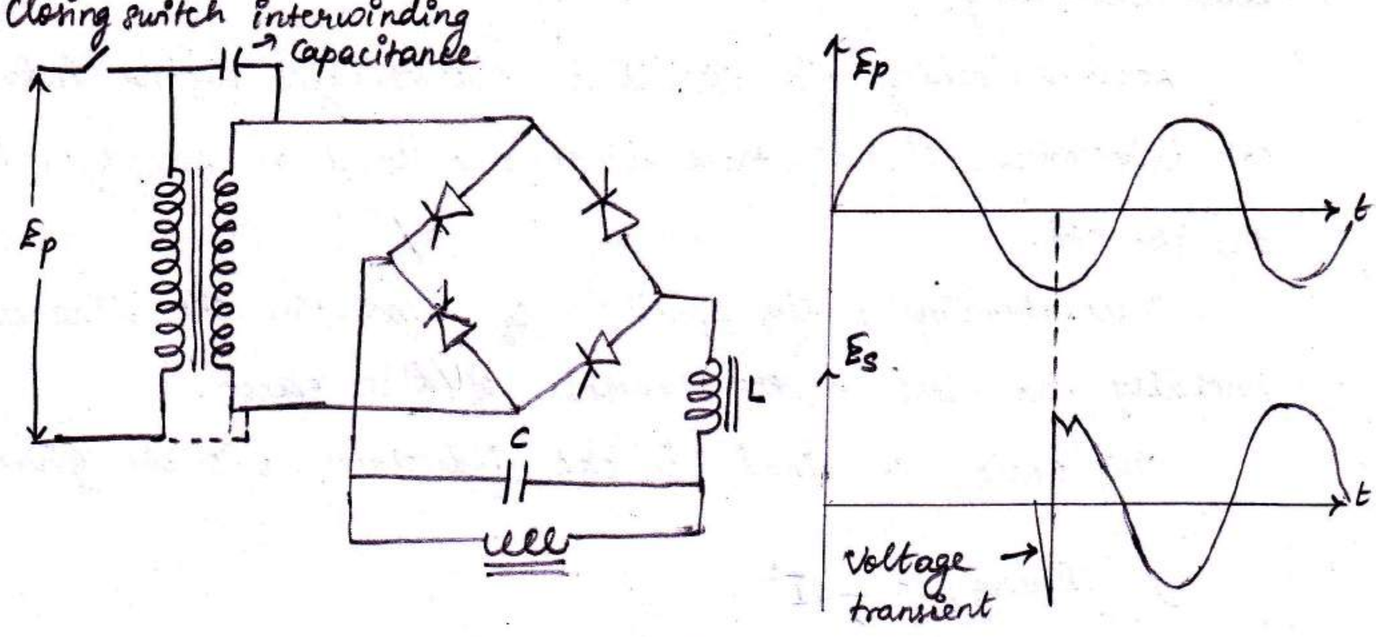
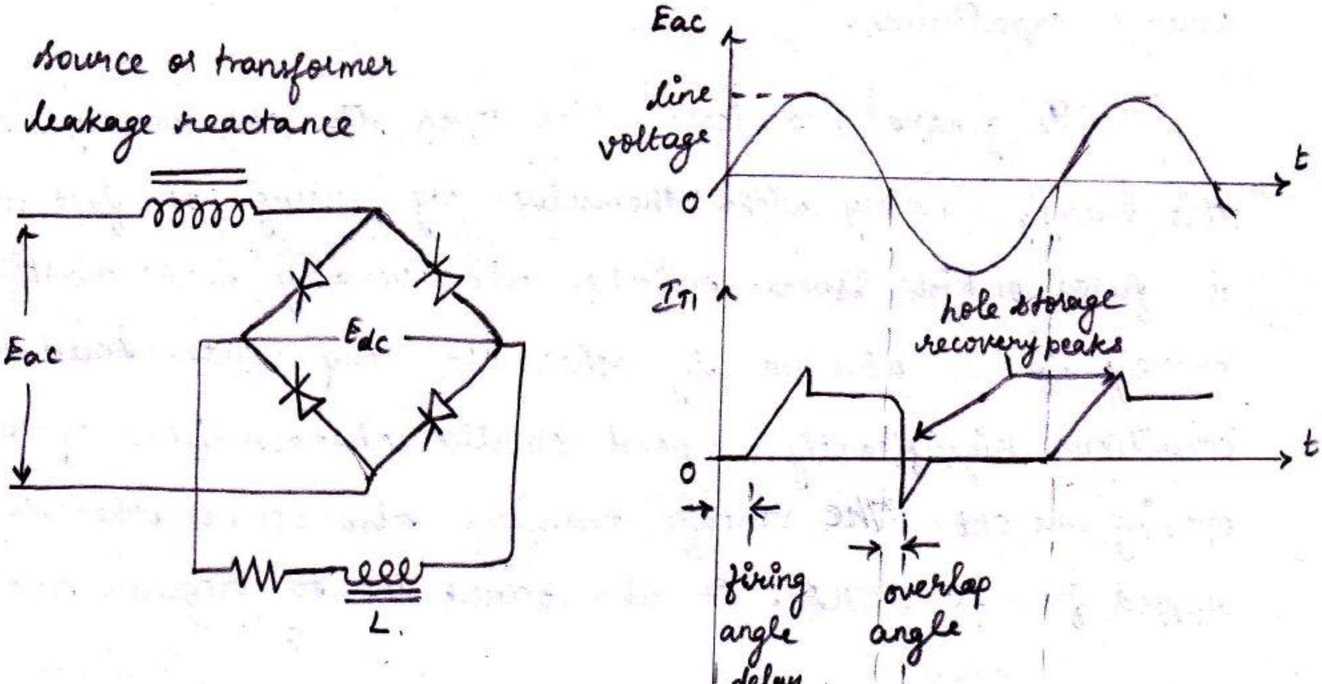


fig (b)



Voltage transient due to energizing step-down transformers

fig (c)



Fig(d) Transients due to reverse recovery of SCRs.

Load switching.

Load switching will result in overvoltages being induced in ckt inductances whether these be on the load or supply side of the thyristor ckt.

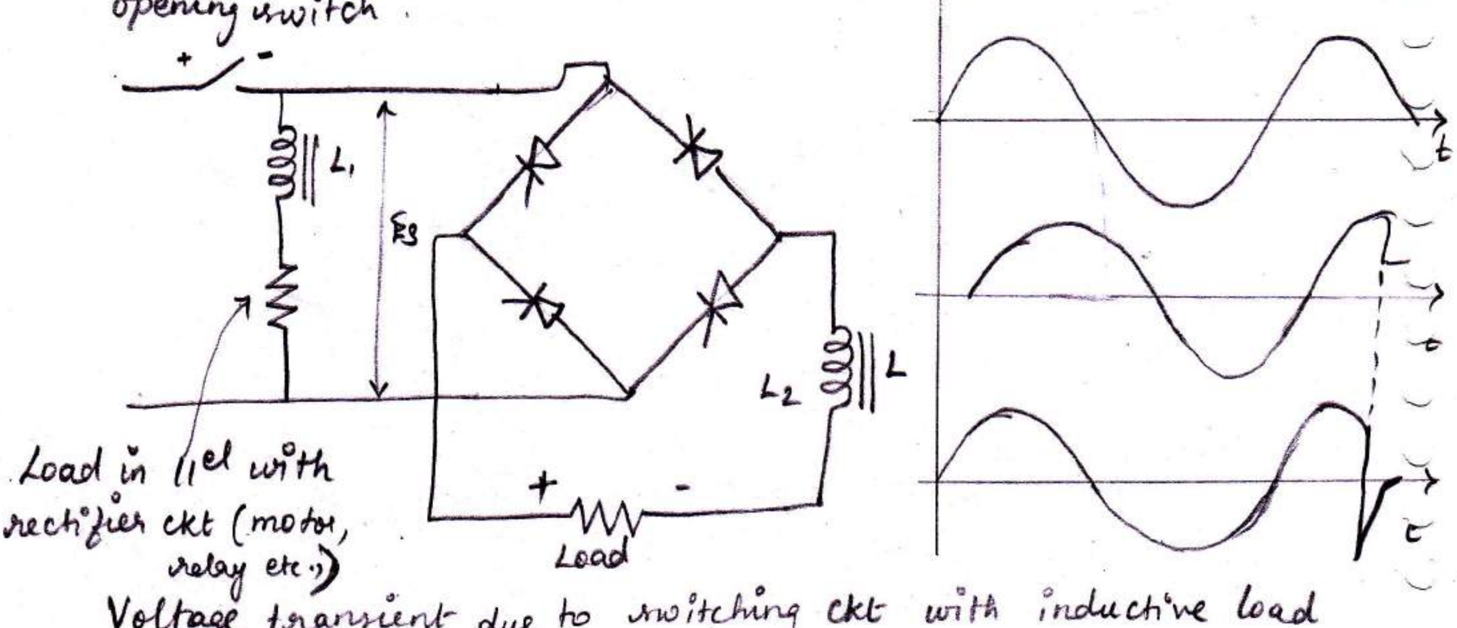
Fuse blowing & the operation of protective ckt breakers are probably the most severe examples of this effect.

The energy contained in ckt inductances will be given by

$$Energy = \frac{1}{2}LI^2.$$

where I is the ct flowing & this will need to be dissipated in the protective components used, without exceeding the device voltage capabilities.

In general, devices which open the ckt slowly, dissipate this energy slowly within themselves by arcing or fast switches, ie, fuses or high speed switches, will usually leave most of the energy to be absorbed by other ckt components. Load switching conditions significantly depend on the characteristics of the switch opening the ckt. The voltage transient also occurs when the load dropped from LC filter. It also occurs due to regenerative load.



Voltage transient due to switching ckt with inductive load across i/p.

B2) a) iii) Heat transfer process

Power-losses in semiconductor devices appear in the form of heat.

The accumulation of heat energy increases the temperature of the internal structure of devices.

Heat transfer takes place in 3 ways:

i) Conduction ii) Convection iii) Radiation

(1m)

Conduction

It is the heat transfer among stationary interfaces by the vibratory motion of atoms or molecules.

Convection

It is the mechanical transport of heat by a moving fluid or gas

The fluid flow may be natural or forced.

Radiation.

Heat energy is converted into electromagnetic radiation in heat transfer by radiation which is absorbed by other components in the vicinity.

(3m).

Design of Snubber network for ac circuit.

The following equation has proved useful in selecting the value of the capacitance required for keeping the voltage transients within the device rating.

$$C = 10 \cdot \frac{VA}{V_s^2} \frac{60}{f} \longrightarrow ①$$

C → minimum capacitance required (in μf)

(VA) → the transformer volt-ampere rating.

V_s → the transformer secondary RMS voltage.

f → operating frequency (2m)

The required resistance to ensure adequate damping can be calculated from the following relationship.

$$R = 2 \tau \sqrt{\frac{L}{C}} \longrightarrow ②$$ (1m)

τ → damping factor; normally taken about 0.65.

R → the required resistance to damp the transient voltage to a desired level.

L → effective circuit inductance

C → minimum required capacitance.

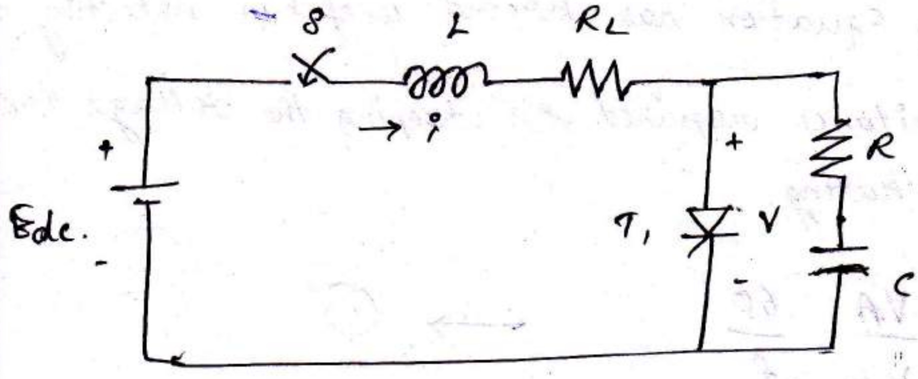
If the max dv/dt for the thyristor is specified, the eqn used in ① to calculate the required value of capacitance is

$$C = \frac{1}{2L} \left(\frac{0.564 \, E_m}{dv/dt} \right)^2$$

E_m → peak i/p line-line voltage.

(2m)

Design of Snubber network for dc circuit.



(2m)

When switch S is closed, the capacitor behaves like a short circuit and SCR in the forward blocking state offers a very high resistance.

The value of capacitor is given as

$$C = \frac{1}{2C}\left(\frac{0.564\ V_m}{dv/dt}\right)^2$$

(2m)

V_m → peak value of supply voltage.

dv/dt is the permissible value dv/dt.

L → source inductand.

And resistance is given as $R = 2\sigma\sqrt{\frac{L}{C}}$

σ → damping factor (usually taken as 0.65)

(2m)

B2) b) iii)

Given :-

dv/dt capability $= 50\ V/\mu s$.

i/p line to line voltage, $E_m = 380V$.

Source inductance, $L - 0.1 mH$

Solution.

$$C = \frac{1}{2L}\left(\frac{0.564\ E_m}{dv/dt}\right)^2$$

$$= \frac{1}{2 \times 0.1 \times 10^{-3}}\left(\frac{0.564 \times 380 \times 10^{-6}}{50}\right)^2$$

$$\boxed{C = 0.092\ \mu f}$$ (2m)

$$R = 2\tau\sqrt{\frac{L}{C}}$$

$\tau = 0.65$ (Assume)

$$\therefore R = 2 \times 0.65 \times \sqrt{\frac{0.1 \times 10^{-3}}{0.092 \times 10^{-6}}}$$

$$\boxed{R = 42.86\ \Omega}$$ (2m)

Staff incharge

HoD/EEE