3B3 2017 CRIB

1. (a) (i) Check the Capacitance:

$$\Delta V = \frac{I}{2fC} = \frac{3}{230\times 2\times 50\times 100n}$$

This is a very large number, so the 100nF is not smoothing the voltage. Therefore, there will be a deadband around 29V, when there is no current drawn for a short period.

$$\sin^{-1}\left[\frac{29}{230\sqrt{2}}\right] = 5^{\mathrm{O}} \text{ (each side of zero).}$$

Average voltage across the 100nF capacitor:

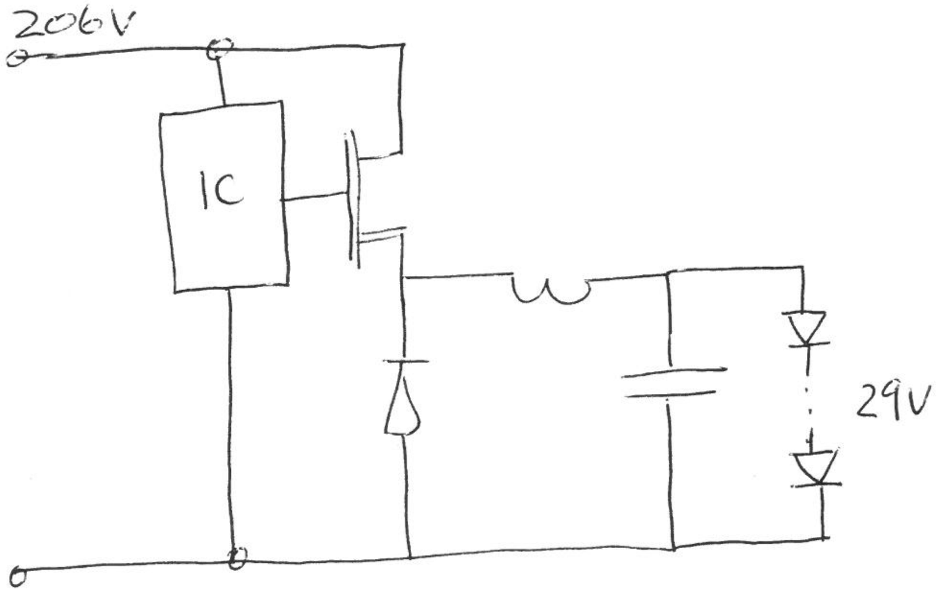
$$\frac{1}{\pi}\left[\int_{\frac{5\pi}{180}}^{\frac{175\pi}{180}} 230\sqrt{2}\,\sin\omega t d\omega t + 29\frac{10\pi}{180}\right] = 2x325x0.996/\pi +1.6$$

Including 2V for diode drops: Ans: 205.7 V

(ii) The regulator R simply acts as a resistor and drops the large voltage. The advantages are:

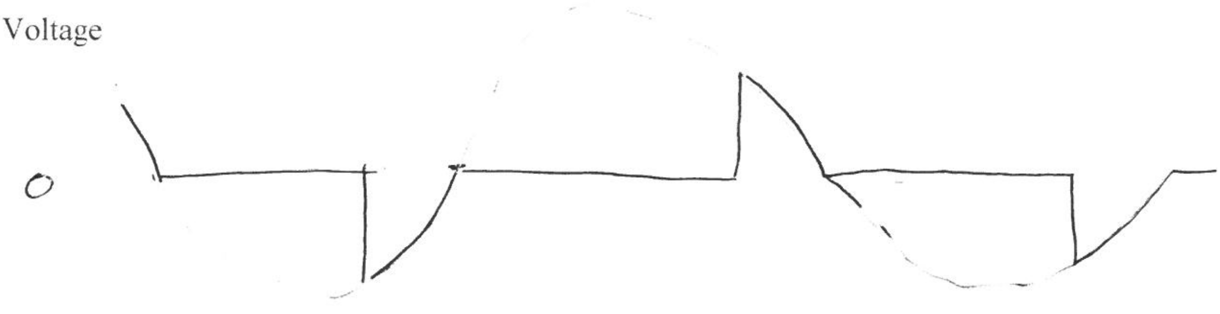
The recifier is full wave so symmetrical ac current waveform;
the current roughly follows the voltage so in phase (so the power factor is very high);
no large smoothing capacitor needed. (This is important as there are millions of such lamps to be deployed in a fully synchronised system.)

(iii) R is the regulator but needs to have the characteristics of a resistor without the losses! This many be achieved by a step down converter or a high frequency resonant half bridge.



(b) (i) Triac dimming works by phase control.

Low Voltage



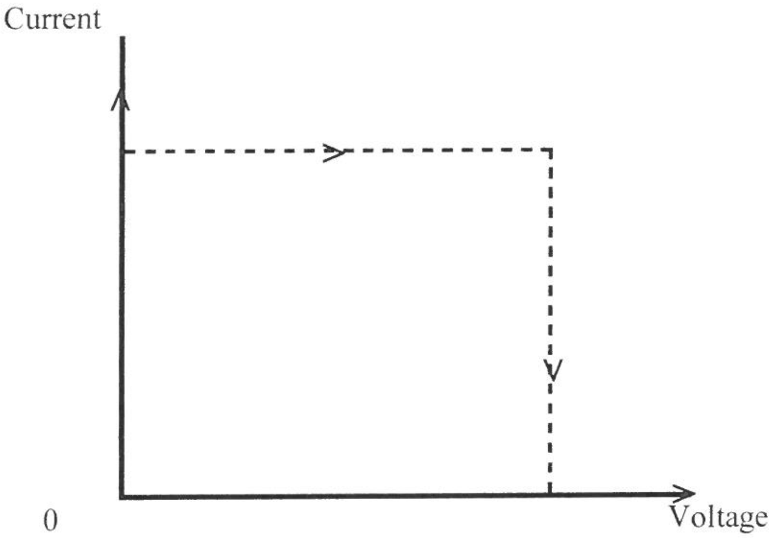
High Voltage

(ii) The instant dv/dt related to the triac firing is imposed on the ac capacitor and the 100nF capacitor in the circuit given. The combined capacitance is very small so the current in the diodes and capacitors at this instant is small and 'safe'. If the dc is 'smoothed', the capacitor is much larger, e.g. 3.3uF and the currrent drawn will destroy the diodes.

2. (a) (i) The MOSFET is a unipolar device. Therefore the bulk material is resistive. Higher voltages need more bulk, so become proportionately more resistive. Automotive is 12 or 24V so well within the comfort range of MOSFETs. Mains voltages of 230V ac are getting to the limit of cost effectiveness, as their resistance grows. Low current LED lamp drivers sometimes use them, since by the time the current is so low the package dominates the cost!

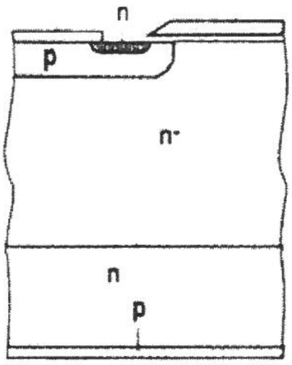
(ii) CGS, CGD, CDS, lables per the MOSFET nodes. CGS is the main channel control, so it's charge determines the channel resistance. CGD is interesting, as the drain source voltage changes during switching so the gate G must absorb or produce that dv/dt current.

(iii) The diode clamping means the voltage does not overshoot the rail voltage (ideal case).



Since voltage and current at the same time is power lost in the MOSFET (like a resistor), the time taken to cross must be minimised to reduce the energy lost per switching event.

(b) Structure of an IGBT:



Soft Punch Through IGBT

Essentially a p layer is added at the bottom. The behaviour may be adjusted by adding an n layer next to the p layer.

(c) The p layer injects holes into the n layer and the IGBT acts like a poor pnp BJT, so turn on and turn off takes some time to complete, so there are extra switching losses at turn off and turn on and these can be very significant, depending on the IGBT voltage rating.

Q3

Answer 4

i) switch on

a) $V_i = L\frac{di}{dt}$, $\Delta I = \frac{1}{L}\int_0^{T_{on}} V_{in}\,dt$

$$\Delta I_{ON} = \frac{V_i T_{on}}{L} = \frac{V_{in}\rho}{Lf}$$

b) switch off

$V_{in} - V_o = L\frac{di}{dt}$ $\Delta I_{off} = \frac{1}{L}\int_{T_{ON}}^{1/f} (V_{in} - V_o)\,dt$

$$= \frac{1}{Lf}(V_{in} - V_o) - \frac{T_{ON}}{L}(V_i - V_o)$$

$$= \frac{(V_i - V_o)}{L}\left(\frac{1}{f} - T_{ON}\right)$$

$$= \frac{(V_i - V_o)(1-\rho)}{Lf}$$

$\Delta I_{ON} = -\Delta I_{off}$

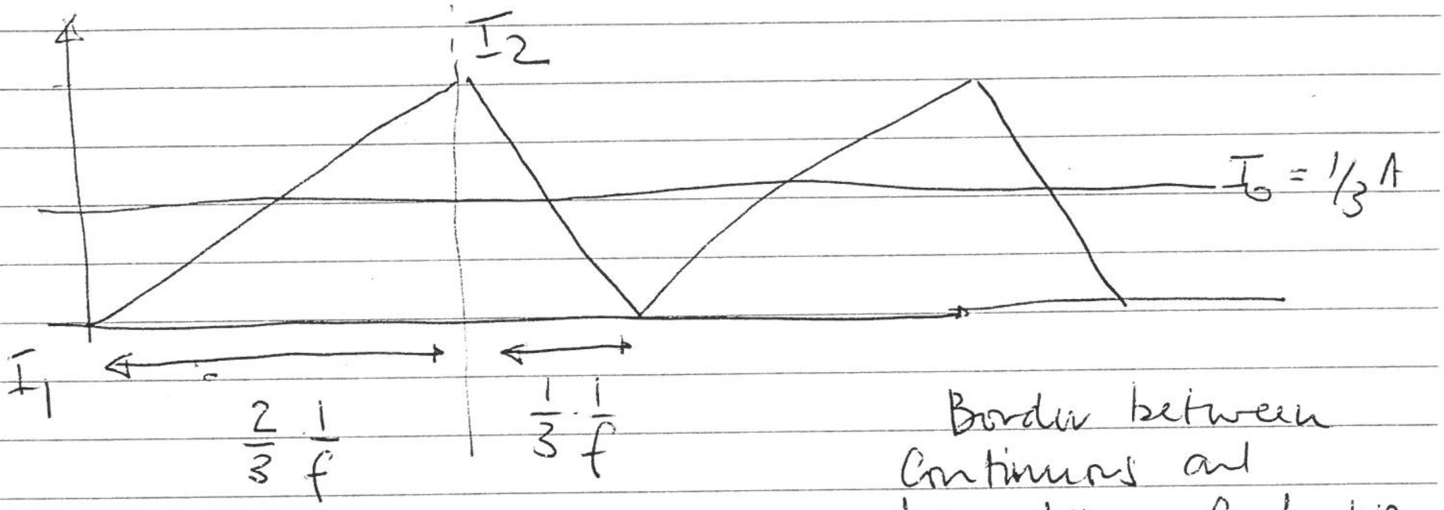
$$\therefore \frac{V_i\rho}{\cancel{Lf}} = \frac{(V_o - V_i)}{\cancel{Lf}}(1-\rho)$$

$$V_i\rho + V_i - V_i\rho = V_o(1-\rho)$$

$$V_o = \frac{V_i}{(1-\rho)} \quad \therefore \underline{\underline{f(\rho) = \frac{1}{(1-\rho)}}}$$

ii) $V_o = \frac{5}{(1-2/3)} = 15V$

iii) For P_o 5W, $I_o = 1/3$ A



Border between Continuous and discontinuous Conduction.

$I_{o(ave)} = \frac{I_2 - I_1}{2}$ $I_1 = 0$ ~~at~~ the ~~[illegible]~~ minimum L value for Continuous conduction.

$I_o = \frac{I_2}{2}$ ∴ $I_2 = \frac{2}{3}$ A

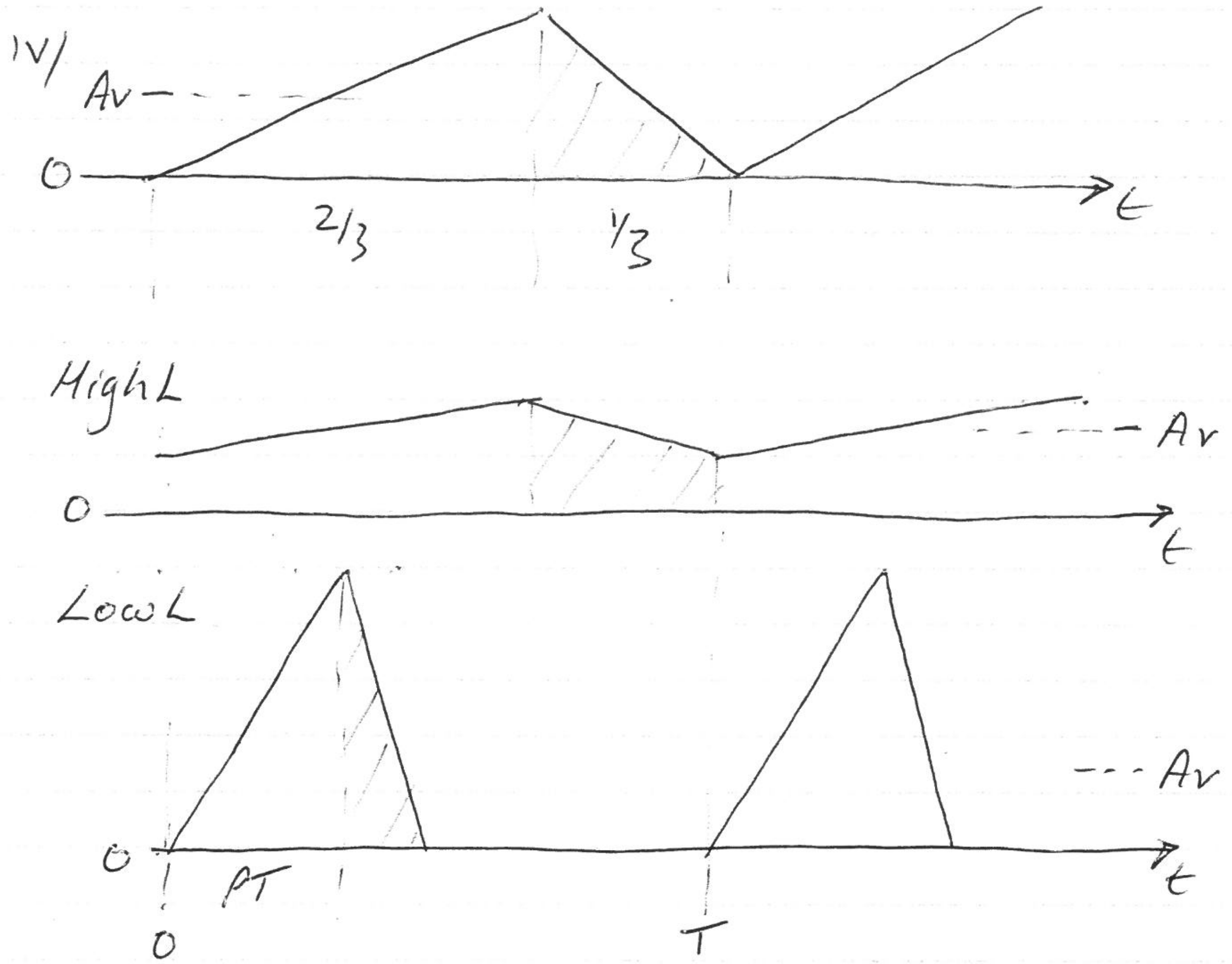
$V_i = L\frac{di}{dt}$ $I_2 - I_1 = \Delta I = \frac{1}{L}\int_0^{\frac{2}{3}\cdot\frac{1}{f}} V_{in}\,dt$

$I_2 = \Delta I = \frac{2}{3}\frac{1}{Lf}\cdot V_{in}$

$\frac{\cancel{2}}{3} = \frac{\cancel{2}}{3}\frac{5}{Lf}$ ~~Vin~~

$L = \frac{5}{100\times10^3} = \underline{\underline{50\times10^{-6}\ H}}$

②



v/ hashed area charges C (and supplies load)

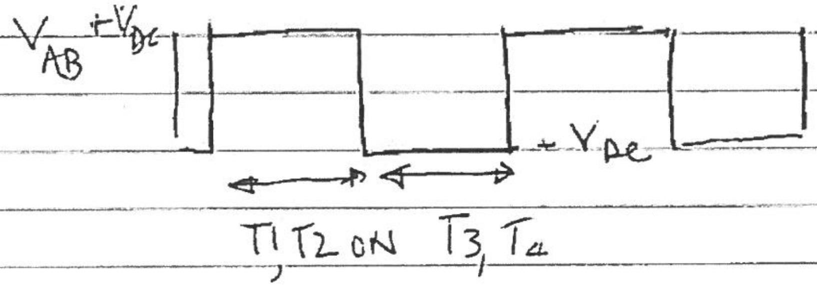
Larger L $\Rightarrow$ smaller C and vice versa.

In all cases C supplies the load through PT and in the low L case also during discont. portion.

Typically C is not expensive and very low loss, whereas losses increase as L increases, so discontinuous Low L usually chosen.

Answers Q4

a) i) V_{DC} can be made a square wave AC signal by switching pairs of transistors T_1, T_2 and T_3, T_4 alternatively. The frequency of switching would then be the square wave frequency.

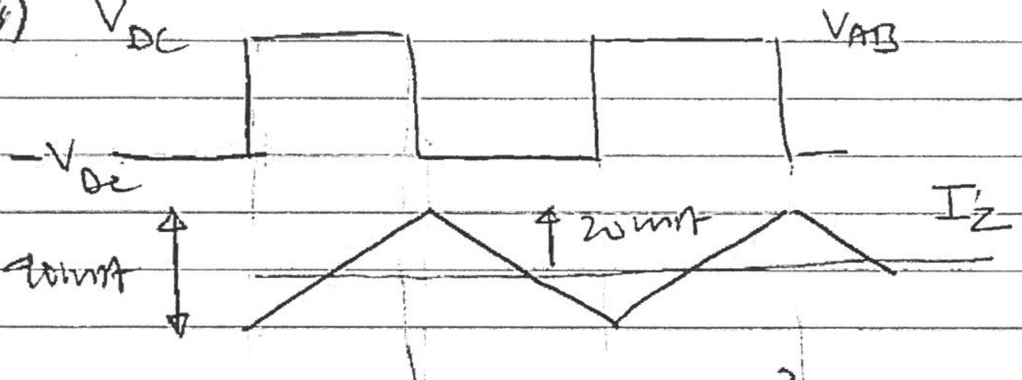


If the load is inductive, then the current through load does not have to reverse before switching cycles.

∴ If current I_{AB} +ve, current flows through Transistor T_1 and T_2. But when T_3, T_4 on to maintain I_{AB} +ve current ~~flow~~ flows through diodes D_3 and D_4.

∴ If current I_{AB} −ve, then the opposite pair of transistors (T_3, T_4) and diodes (D_1, D_2) conduct current.

ii~~b~~)



* Can also use

$V_{DC} = L\frac{di}{dt}$

L = 1

$\frac{di}{dt} = \frac{40\times10^{-3}}{0.5\times10^{-3}} = 80$

$\therefore V_{DC} = 80$

At 1kHz $Z = 1 + j2\pi10^3$

Take inductive part of load >> resistive part

Average AC current is $\frac{20mA}{2} = 10mA$

AC current amplitude = 20mA

Consider the first harmonic of the AC current wave and the voltage wave

Fourier components for a triangular wave (~~etc~~ available in data book?)

$\frac{8}{\pi^2 n^2}$ n = harmonic - only odd harmonics

Fourier components for a square wave

$\frac{4}{\pi n}$ n = harmonic - only odd harmonics

$\therefore n = 1$ r.m.s

$$\omega L \times \underline{I}(\omega) = V(\omega)$$

$$\frac{1}{\sqrt{2}} \cdot \frac{4}{\pi} V_{DC} = 2\pi \times 10^3 \cdot \frac{8}{\pi^2} \times 20 \times 10^{-3} \frac{1}{\sqrt{2}}$$

$$\boxed{V_{DC} = 80V}$$

②

a) iii) Power loss in R for harmonics

$$I^2(n\omega) \cdot R = P(n\omega)$$

for 3rd harmonic

$$\left[\frac{40\times10^{-3}}{\sqrt{2}} \cdot \frac{8}{\pi^2 \cdot 9}\right]^2 \times 1 = P(n\omega)$$

$$\frac{400\times10^{-6}}{2} \cdot \frac{64}{81}\,\frac{1}{\pi^4} = P(n\omega)$$

for 1st harmonic

$$\left[\frac{400\times10^{-6}}{2} \cdot \frac{64}{\pi^2}\right] = P(\omega)$$

$$\therefore \quad \frac{P(n\omega)}{P(\omega)} = \frac{1}{81}$$

∴ For the triangular current wave form higer harmonic (unwanted) losses are v. small compared the fundamental (wanted) power.

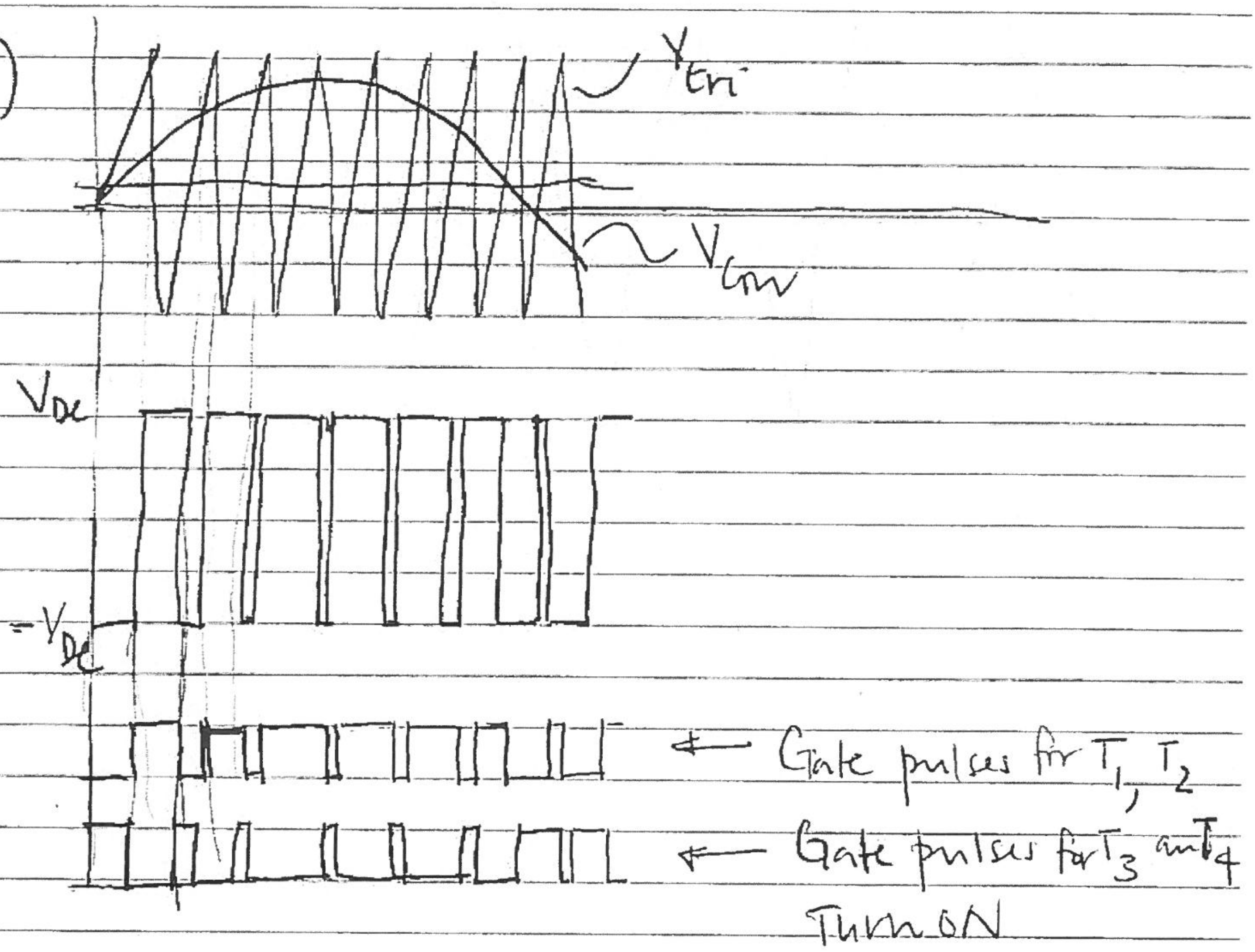
$$\frac{4^2}{\pi^2}\left(\sin\omega t + \frac{1}{3}\sin 3\omega t + \dots\right)^2$$

But $R + j\omega L \Rightarrow j3\omega L$ for 3rd

$$\Rightarrow \frac{1}{3^2} \times \frac{1}{3^2} = \frac{1}{81}$$

③

b)



The gate pulses are derived by having the desira sinusoidal voltage wave for analogue ~~s~~, V_{con}, sampled by a triangular wave V_{tri} which has a much higher frequency.

The gate pulses are derived such that, T_1 and T_2 in Fig Y are 'ON' when $V_{con} > V_{tri}$ and T_3 and T_4 are 'ON' when $V_{con} < V_{tri}$. As shown above

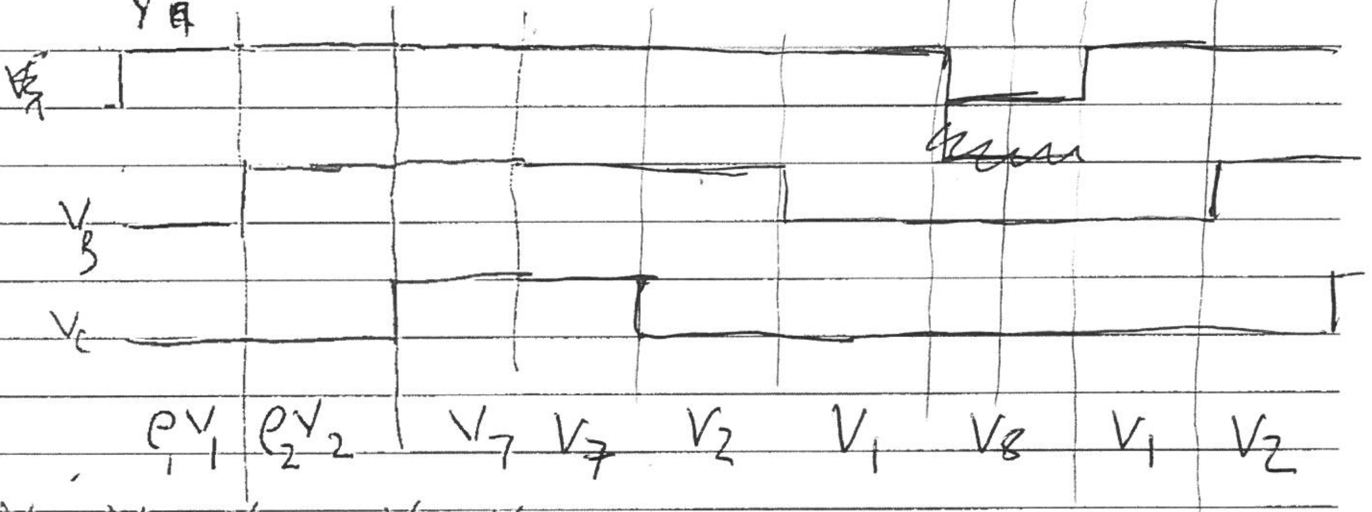
④

c) Are required to determine the position (angle) and magnitudes of V_n.

States V_1 and V_2 are shown.
The duty cycles of switching states V_1 and V_2 determine the angle θ. Changing duty cycle chages θ (i.e. moves V_n). ~~The zero sta~~

ii) The zero states are used in between switthing of V_1 and V_2 states to set the magnitude of V_n relative to V_1, V_2. It has to have a constant magnitude as it moves through the zones.

i)



$V_A - V_B = V_2$ $V_A = V_1$

iii) In direct-direct the switching ~~the~~ sequence in any given zone is the same e.g. V_1, V_2, V_7, V_1, V_2 with V_7 used as zero state in zones 1, 3, 5, 7 and V_8 in zones 2, 4, 6.

⑥