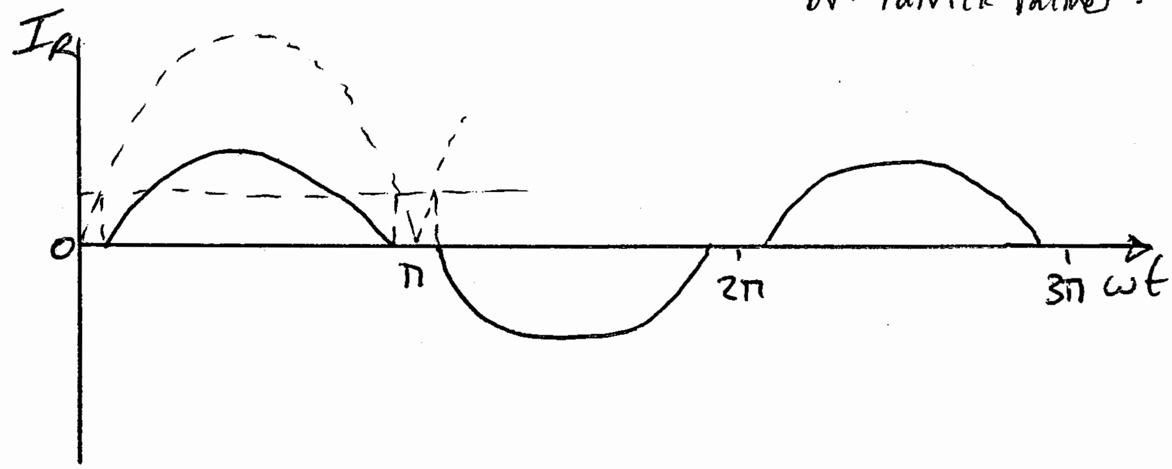
3B3 CRIB 2006

PART IIA
3B3 : Switch-mode electrics
Principal assessor: Dr. Patrick Palmer.

1/ (a)



12.9V is the average after diodes. (2V)

∴ 14.9V before the diodes ignoring small loss of conduction angle.

$$\therefore \frac{2\sqrt{2}}{\pi}\hat{V} = 14.9 \qquad \hat{V} = 23.4V$$

For conduction angle θ

$$23.4 \sin\theta = 3.6 + 2\times 1$$ — diode voltages.

$$\theta = 13.9°$$

So conduction over $\underline{152.2°}$ (8.46mS)

A similar answer is found ignoring the diode's voltages

$$\frac{2}{\pi}\int_{13.9°}^{90°} 23.4 \sin\omega t \, d\omega t = 14.46V$$ — close to 14.9V!

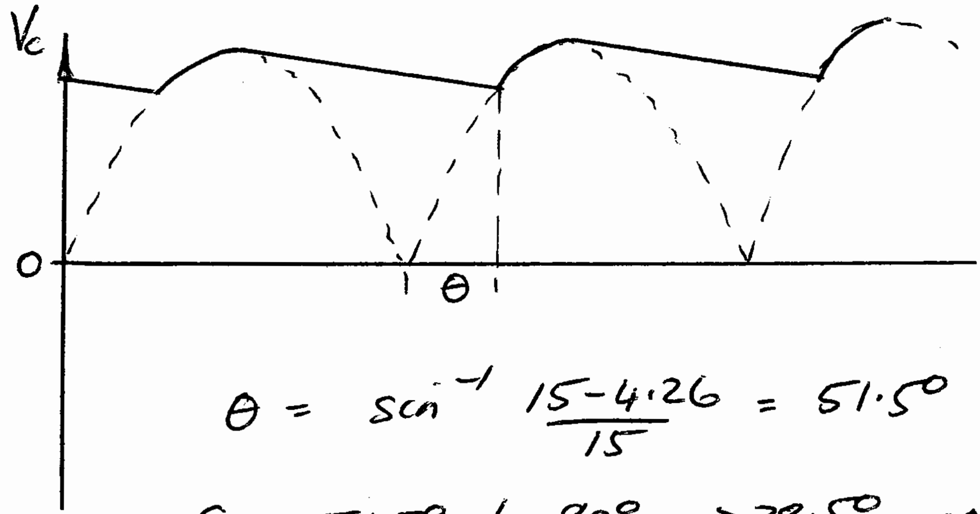
$$\frac{14.46 - 5.6}{R} = 0.5 \qquad \underline{R = 17.72\,\Omega}$$

Safe, Cheap, Reliable, Low peak current, good pf, Low harmonic distortion, Any 3!

1,(b) Capacitively smoothed!

$I = C\frac{dV}{dt}$ $\Delta V = \frac{0.2 \times 10m}{0.47m} = 4.26V$

$12\sqrt{2} - 2$ diodes $\Rightarrow 15V$



$\theta = \sin^{-1} \frac{15-4.26}{15} = 51.5°$

Say $51.5°$ to $90° \Rightarrow 38.5°$ or 2.14 mS

$I = C\frac{dV}{dt} = C\omega\hat{V}\cos\omega t \Big|_{\omega t = 51.5°}$

$= 470\mu . 2\pi . 50 . 15 \times 0.622$

$= 1.38A$ (Repetitive)

In the question as originally posed, the LiIon battery was 3.7V and the bridge gives 8.8V so a SMPS is needed for a high efficiency design, reducing the current drawn from the rectifier to $\frac{0.2 \times 3.7}{8.8} = 0.084A$.

The students all assumed a low efficiency design!

2 (a) Losses on switching

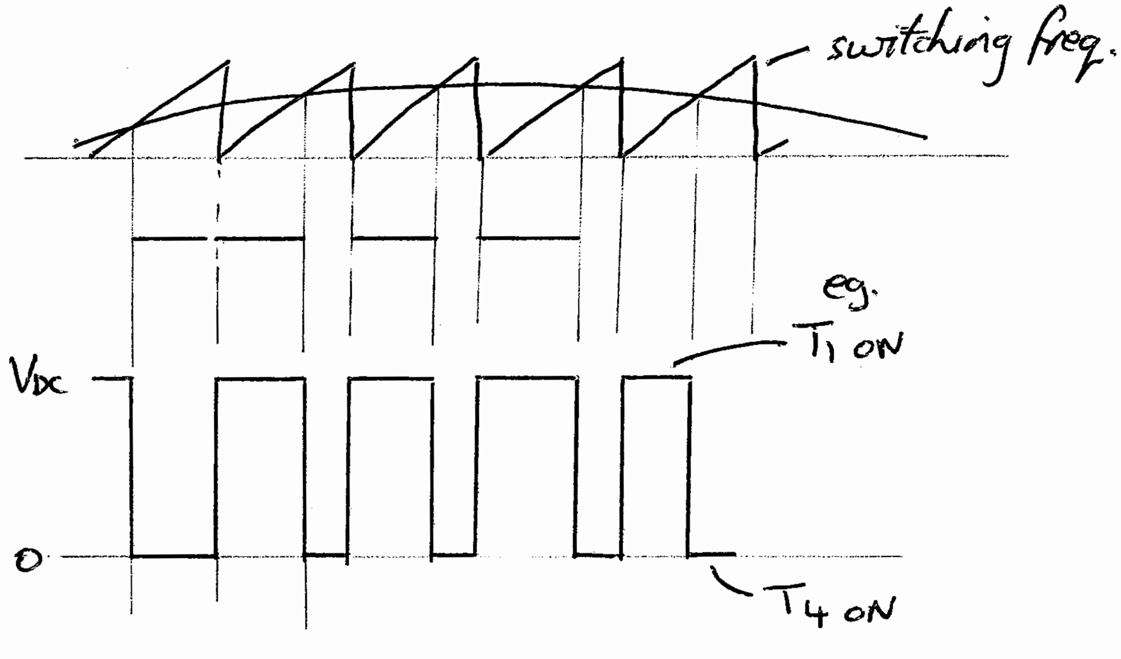
Harmonics at the load / Filtering.

Audibility.

Ease of generation.

Deadtime. <u>Any three</u>

(b) Naturally sampled – compare sawtooth to the reference sinewave. Three sinewave references are needed, displaced by ±120°



The sawtooth (or triangular) wave should be an odd, integer multiple of 3 times the reference waveform frequency.

2 (c) Using the method of part (b) with Fig 2. gives a fundamental output voltage waveform $m \frac{V_{DC}}{2} \sin \omega_1 t$, where ω_1 is the angular frequency of the sinusoidal reference waveform. m is the modulation index

Since it is a three phase bridge, the outputs are similar but displaced by $\pm 120°$

rms line voltage $= V_a - V_b$

$= \sqrt{3}\, \hat{V}_a / \sqrt{2}$ — rms

$$|\hat{V}_a| = m \frac{V_{DC}}{2}$$

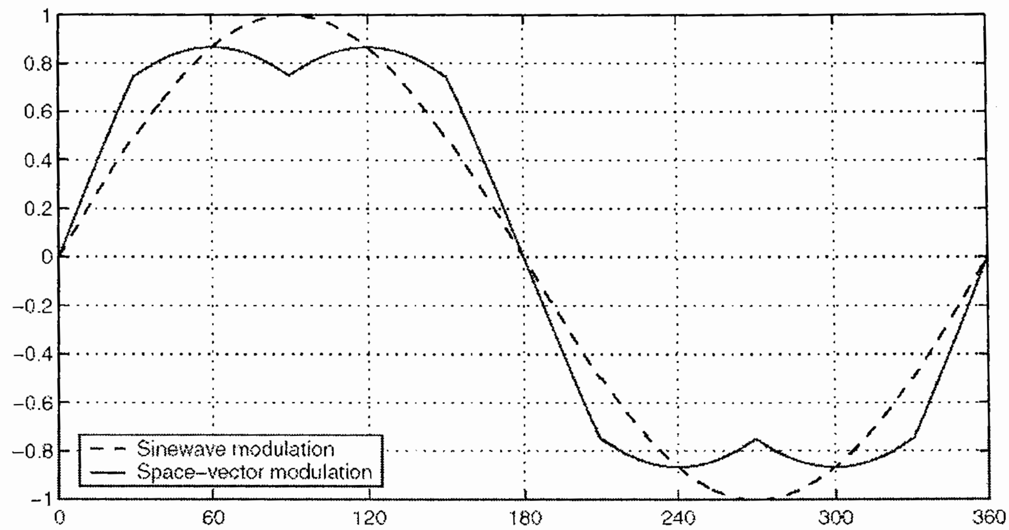
When m exceeds 1, overmodulation occurs and pulses of the output voltage are lost and the output tends to a square-wave. Thus harmonic distortion is increased. The output is no longer proportional to m.

2(d) In space vector modulation, pulses are dropped intentionally to reduce the switching. In SVM this does not necessarily increase the harmonics or make the output non-linear with m, as the line voltage is given by $V_a - V_b$.

i.e. $\rho_A V_A - \rho_B V_B$

Perhaps best seen in the effective reference waveform, ρ_A and ρ_B can compensate for each other, so one leg is modulating even if the other is not!

12.3.1 Comparison of the Bridge leg voltage output (filtered)

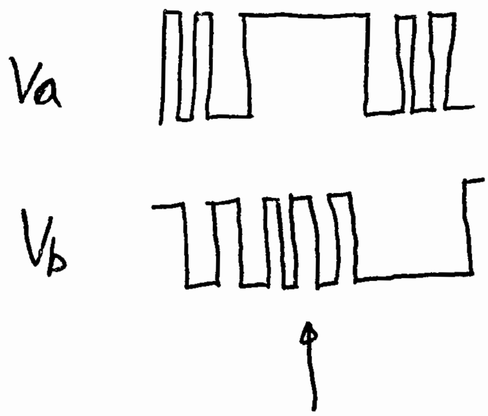


So the SVM can have a larger fundamenta[l]

Alter Sine gives a circle for the bridge; SVM gives a hexagon $2/\sqrt{3}$ ratio at the largest p[...]

2/(d) cont.

<u>Alter II</u>



$V_a - V_b$ is still modulated

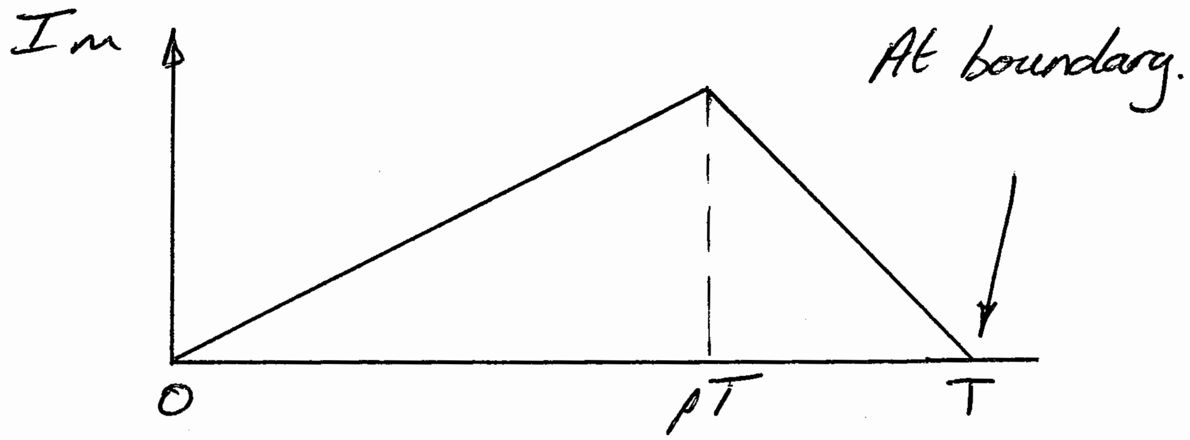
In many sinewave schemes, third-harmonics are added to the reference waveform. This has a very similar effect on the modulation linearity, although has no effect on the switching losses.

Any of the above

3/ 170V from 12V with 1:5 transformer

$\frac{170}{5}$ is reflected back so the transformer recovers with $\frac{170}{5} + 12V$ applied to the MOSFET $\Rightarrow$ <u>46V</u>

Transformer is energised by 12V



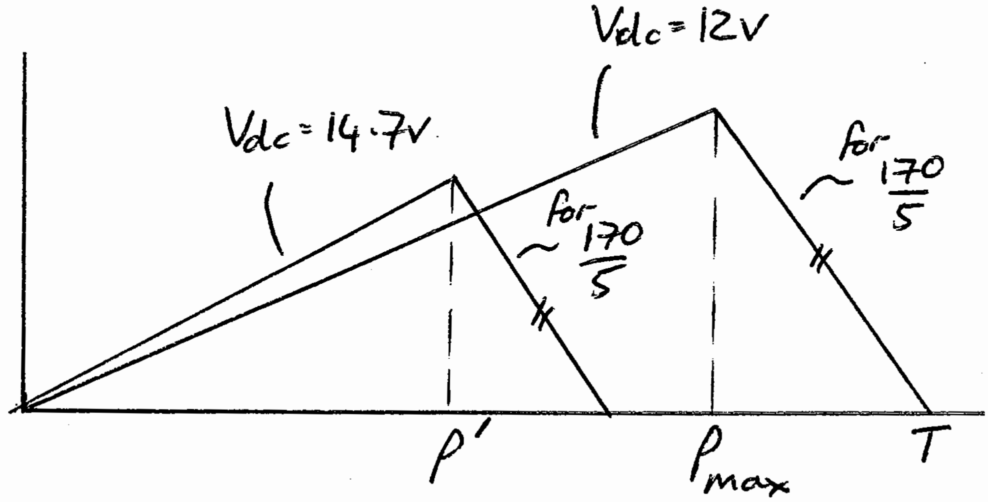
$$12\rho T = \frac{170}{5}(1-\rho)T$$

$$\rho = 34/46 = \underline{0.739}$$

$$100W = 0.739 \times 12 \times \frac{\hat{I}}{2} \qquad \hat{I} = 22.55$$

A 60V, 25A Mosfet is very effective, as low voltage mosfets are very low $R_{DS\,ON}$. Higher voltage Mosfets have a higher $R_{DS\,ON}$ for the same area. Also the peak current here is reasonably low and losses are $I^2 R_{DS_{ON}}$. So 1:5 has put it in a good place for Mosfets.

3/(cont) $\frac{1}{2}$ Load; 14.7V.



$$\hat{I} = \Delta i = \frac{1}{L}\int_0^{\rho T} V_{dc}\,dt = \frac{V_{dc}}{L}\rho T \quad \text{—— (1)}$$

Energy from supply: $V\int_0^{\rho T} I\,dt = V\frac{\hat{I}}{2}\rho T$

$$12\,\frac{\hat{I}}{2}\,0.739T = 2\times\frac{\hat{I}'}{2}\,\rho' T\,.\,14.7$$

$$\overset{(1)}{\Rightarrow} \quad 12^2 . 0.739^2 = 2 . 14.7^2 \rho'^2$$

$$\rho' = \frac{1}{\sqrt{2}} . \frac{12}{14.7} \times 0.739 = \underline{0.43}$$

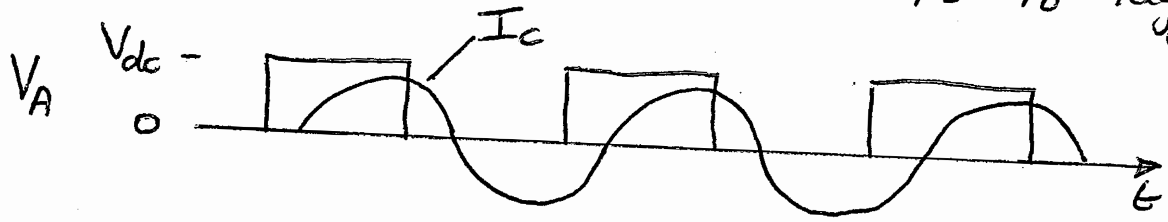
Noting that $\frac{1}{2}L\hat{I}^2$ is transferred each cycle

$$\frac{1}{4}L\hat{I}^2 = \frac{1}{2}L\hat{I}'^2 \quad \therefore \quad \hat{I}' = \frac{\hat{I}}{\sqrt{2}} \quad \text{then use (1)}$$

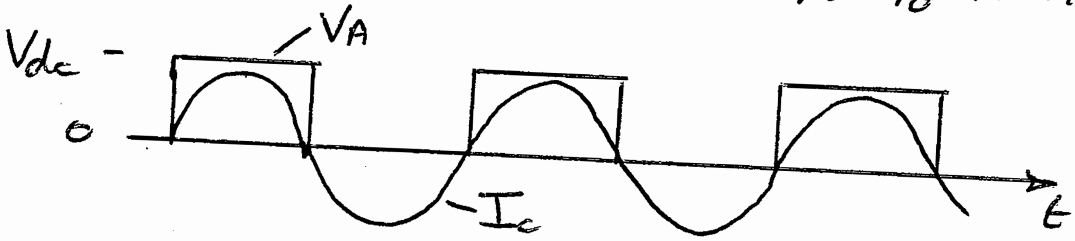
Similar triangles for the <u>170V side</u> would also give this result.

4 (a)

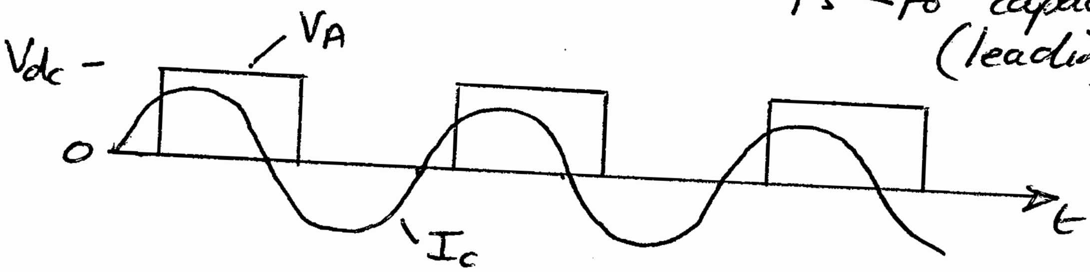
$f_s > f_o$ lagging



$f_s = f_o$ resonance



$f_s < f_o$ capacitive (leading)



$f_s > f_o$ Hard switched turn off; No diode recovery problem

$f_s = f_o$ ZCS, at turn on and off; no power control by modulation.

$f_s < f_o$ No turn-off losses; Diode recovery currents

The extra capacitor is only for $f_s > f_o$, when the capacitor acts to take the current from the switching device at turn off. The capacitor needs to be small to not affect f_o.

4 / (a) cont.

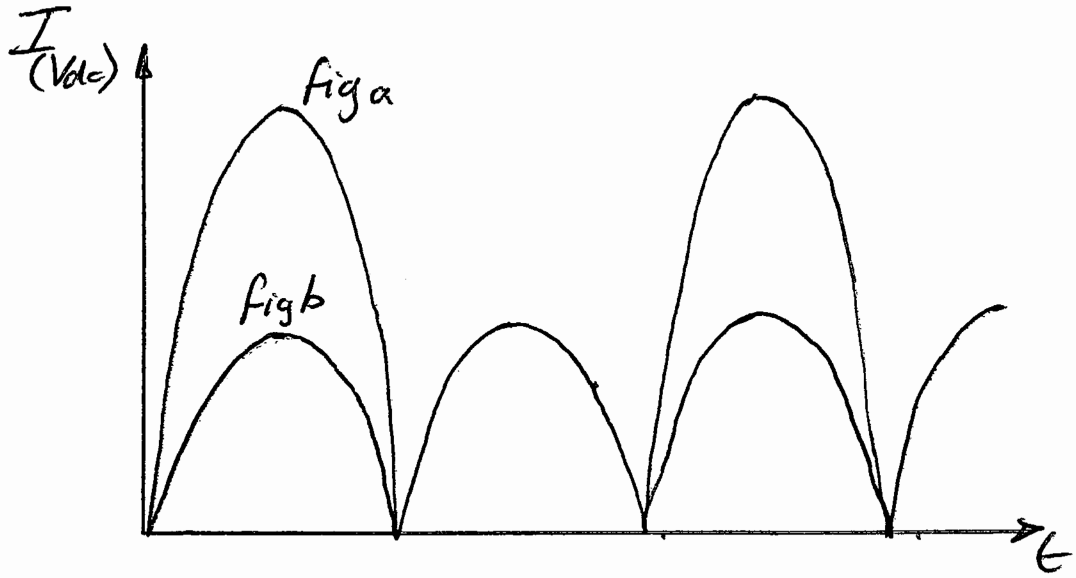
10% of C will hardly affect f_0 as

$f_0 = 1/\sqrt{LC} \approx 1/\sqrt{LC \times 1.1}$; Similarly with Q

Choose 0.1C = <u>0.01 μF</u>

(b) We are interested in the ac operation:

The two capacitors act in parallel ∴ <u>C' = 0.05μ</u>



$Z_0 = \sqrt{\frac{L}{C}} = \sqrt{\frac{1}{0.1}} = 3.3\Omega$ $\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\mu\sqrt{0.1}}$

$Q = \frac{\omega_0 L}{R} = \frac{Z_0}{R} = 3.3$ Good filtering action!

$V_{ac} = \frac{48}{2} \cdot \frac{4}{\pi} = 30.56 \Rightarrow$ <u>30.56 A</u>

fig b

∴ for fig b <u>61.12A</u>

PtIIA : 3B3: Switch mode electrics 2006. (Principal assessor: Dr P. R. Palmer)

ANSWERS

1.(a)	8.46 ms	17.72 Ω		
(b)	2.14 ms	1.38 A		
2.				
3.	0.739	22.55 A	46 V	0.43
4.(a)	0.01 μF			
(b)	0.05 μF	61.12 A (a)	30.56 A (b)	