PART IIA 3B3 2003 CRIB

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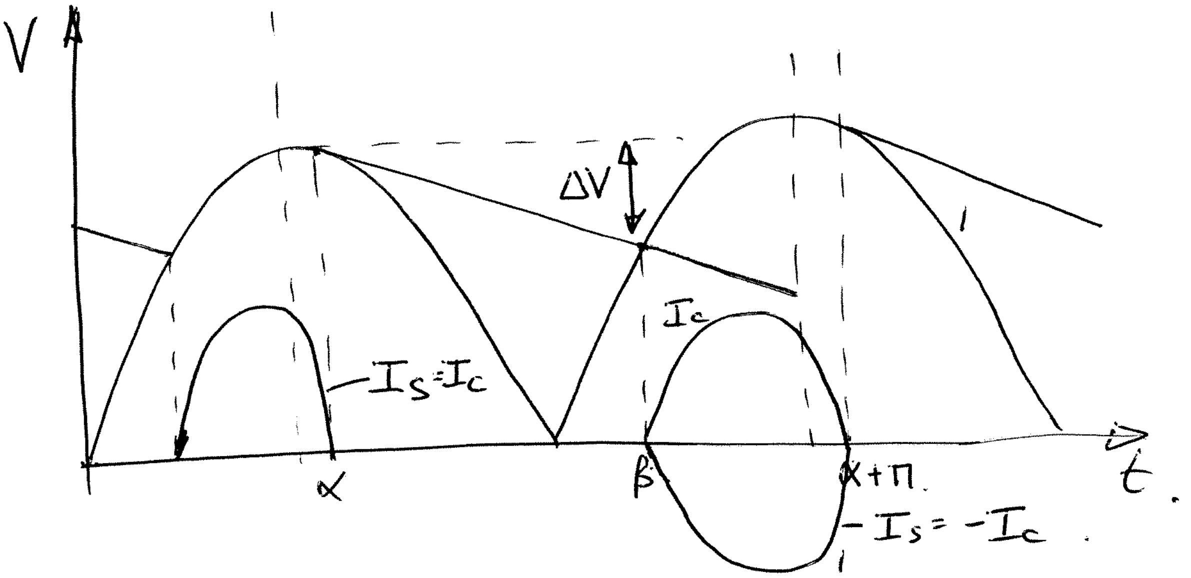
1 (a)



Charging from β to α+π each half cycle.

Disharging from α to β, with ripple of ΔV

For simple equation assume

1/ Charging time is negligible.

2/ Linear decay in voltage.

$$\text{so} \quad I = C\frac{dV}{dt} = C\frac{\Delta V}{\Delta T}$$

$$\text{Ripple } \Delta V = \frac{I \Delta T}{C} = \frac{I}{2fC}. \quad 4$$

Taking large currents at the top of the supply voltage waveform causes problems due to the impedance of the supply. The voltage peak gets flattened – $\frac{1}{3}$ harmonic. 2

1(b).

$I = C \frac{d}{dt} 415\sqrt{2} \sin\omega t$.

5% → $\sin^{-1} 0.95$

72°

$I = C \frac{dV}{dt}$.

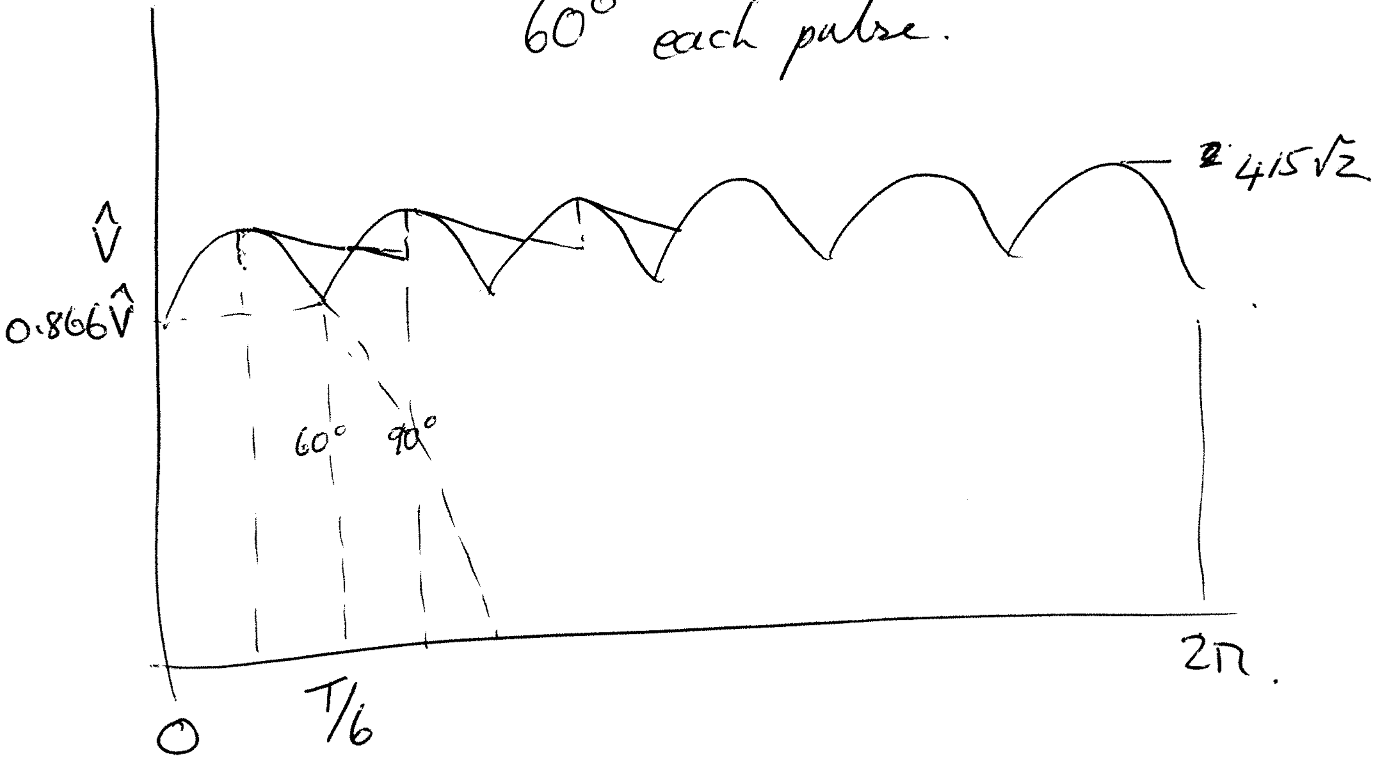
$= C . 415\sqrt{2} . 2\pi . 50 \cos \cancel{80} 72°$

$= 11.36m . 415.\sqrt{2} . 100\pi . 0.\cancel{174}$ 312

$= \cancel{363A} . \underline{\underline{653A}}$ 2

$\Delta V = \frac{I}{C} . \Delta T$.

60° each pulse.



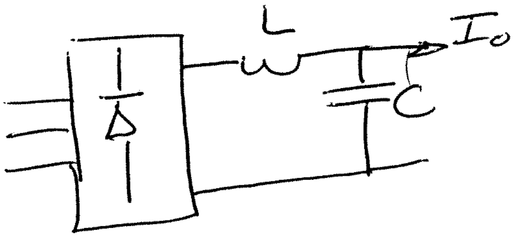
5% ripple.

$\Delta V = \frac{I \Delta T}{C}$

$C = 100A . \frac{1}{6f} . \frac{1}{415 \times \sqrt{2} \times 0.05}$

$= 11.36 mF$ 4

For 1% ripple



Treat it as a filter to the $3\omega_0$ frequency.

$\frac{1}{1+ -9\omega^2 LC} = 0.01$

1(b) cont

$$\frac{1/j\omega 3C}{1/j\omega 3C + \cancel{1}/j\omega 3L} = \frac{1}{1 \cancel{+} - 9\omega^2 LC} = \cancel{0.01 \times 1} \; 1/14$$

3rd ≃ $0{\cdot}14 \times 415\sqrt{2}$ pk-pk

Reduced to $0.01 \times 415\sqrt{2}$

Ratio of 14

$$1 - 9\omega^2 LC = \cancel{100}\; 14$$

$$\left|9\omega^2 LC\right| = \left|\cancel{99}\; 13\right|$$

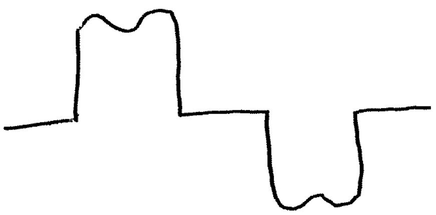
$$\omega^2 LC = \cancel{99}\,13/9$$

$$L = \cancel{11/63} \quad \frac{\cancel{99}\,13}{9C\omega^2}$$

$$= \frac{\cancel{99}}{\cancel{9} \cdot 11.36m \times (314)^2} \cdot \frac{13}{9}$$

$$= \cancel{9.8mH} \quad \underline{\underline{1.29mH}}$$ 4

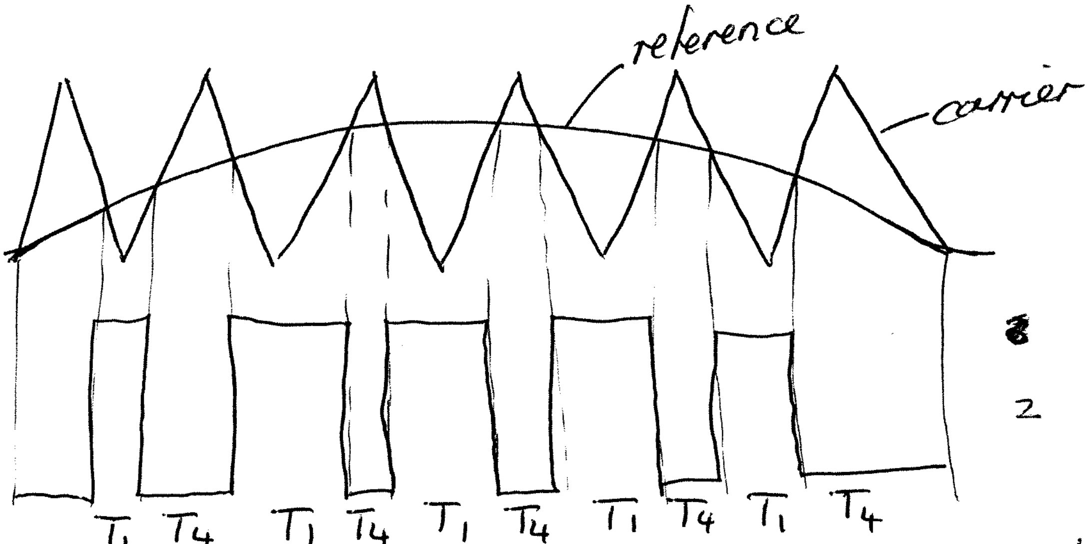
The inductor keeps the current Io flowing, even when the supply voltage is dropping, so the supply current become quasi square with the ripple on top.



2

2 a/ IGBTs are good devices for voltages between 600V and 3.3kV (or above). They are available in current ratings from about 25A to 2500A. IGBTs have a MOS gate so the drive requirements are pretty easy compared to Bipolars, GTOs. IGBTs may also be operated at high frequencies, depending on the rating – inaudible, reduced harmonics.
3

Sinusoidal pwm control signals are created using a carrier frequency waveform and a sinusoidal modulating waveform (reference)



Not a great sketch!

In the inverter:

switches: top	1	3	5
lower	4	6	2
	V_A	V_B	V_C

2 a cont

The three legs are controlled in a similar fashion, with there being 3 reference waveforms, which are 120° apart (0°, 120°, 240°), to give the correct phasing of the outputs V_A, V_B, V_C. Clearly analog circuits may be used, but these are unattractive for such complexity. A $\frac{1}{4}$ cycle of pwm may stored and duty ratio modulation added to it*. Then three pointers are clocked through it at a variable rate.

* for varible voltage.

Or a large ROM lookup table used. Proprietary chipsets seem to have disappeared with the advent of DSPs and chip microprocessors. 2

Gear changing is required to keep the switching frequency in a small range, while the reference frequency changes ~ switching losses are stable, delays accomodated and integral, odd integer ratio of carrier to reference maintained (no subharmon 2

2(b)

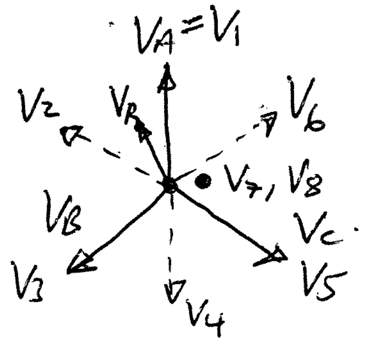
States.

A	B	C	State.
1	0	0	V_1
1	1	0	V_2
0	1	0	V_3
0	1	1	V_4
0	0	1	V_5
1	0	1	V_6
1	1	1	V_7
0	0	0	V_8

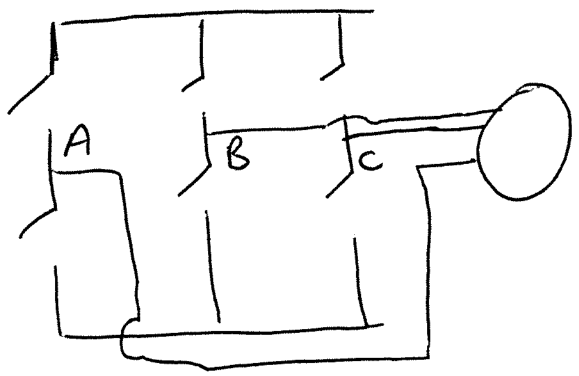
4

The voltages produced by the bridge can be considered as summing as a vector, where V_A, V_B and V_C are 120° apart.

eg. $V_1 \Rightarrow V_{AB} = V_{DC}$, $V_{AC} = V_{DC}$.



2



For V_R as drawn.

$$V_R = m_1 V_1 + m_2 V_2 \quad \text{for SVM.}$$

$$V_R = m_A V_A + m_B V_B + m_C V_C \quad \text{for PWM}$$

So C is not switching if V_8 is the zero state used. 4

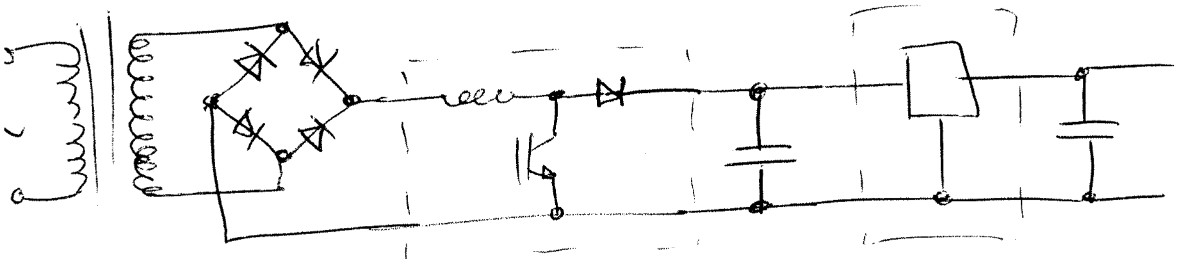
PWM=SVM for massive overmodulation !

3. (a) 2 advantages: 1. Efficiency of SMPS is greater.

2. Energy storage elements are smaller due to higher operating frequencies (these include isolation transformer).

2

Example circuit: SMPS (boost converter) provides power factor correction for linear regulator circuit:



PFC

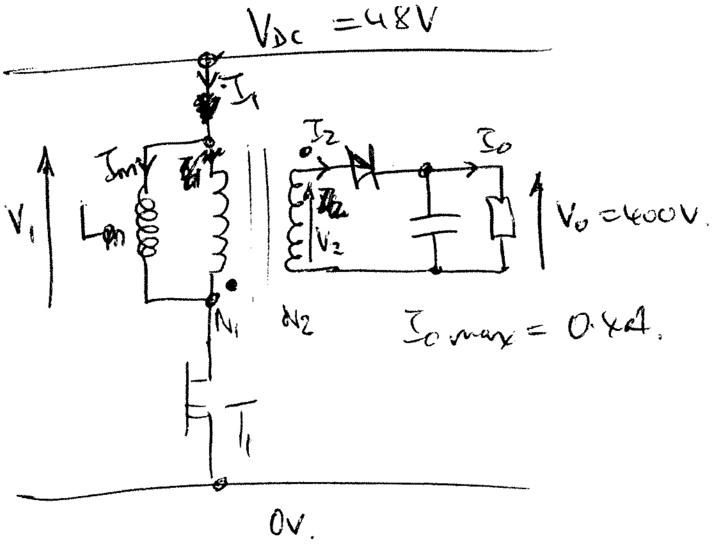
(Produces sinusoidal current in diodes and transformer ⇒ low distortion, good power factor)

Linear regulator.

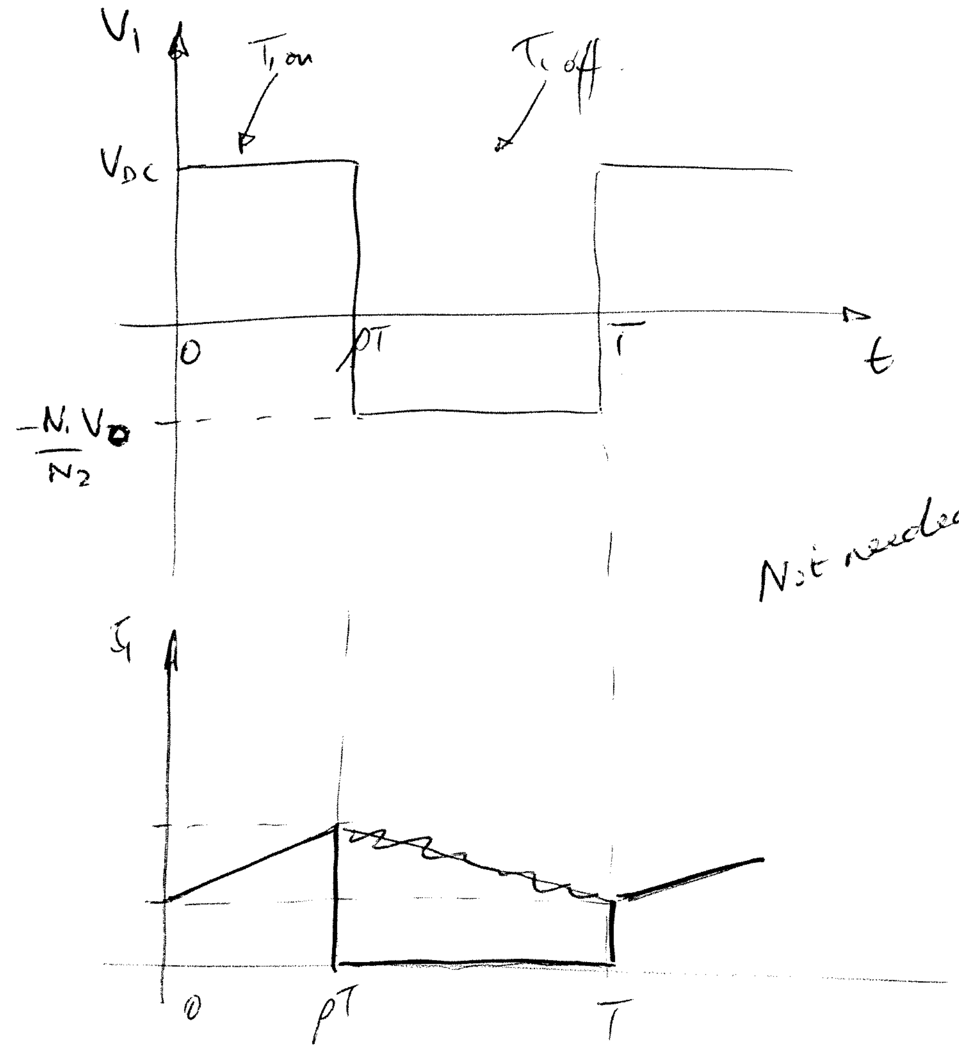
(Provides better ripple rejection from PFC regulator for low-noise applications).

4

3 (b).



$I_{o\,max} = 0.4A$.



Not needed.

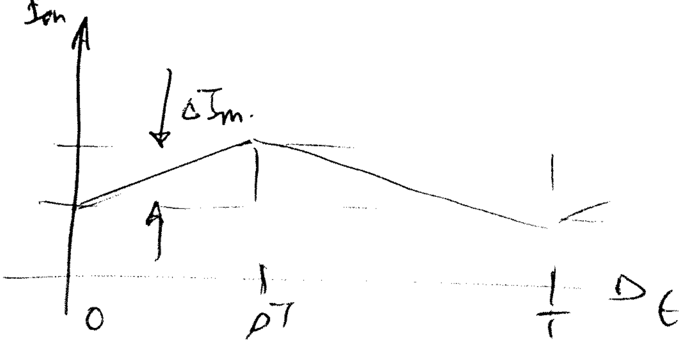
$$\Rightarrow N_2 I_2 = (I_m - I_1) N_1$$

$$\Rightarrow I_2 = \frac{N_1}{N_2}(I_m - I_1)$$

Now $I_2 = 0$ for $0 \le t < \rho T$

$I_1 = 0$ for $\rho T \le t < T$.

$\Rightarrow I_m$ is:



Considering $V_1 = L_m \frac{dI_m}{dt}$.

$$\Rightarrow T_1 \text{ on: } V_{DC} = \frac{L_m \Delta I_m}{\rho T} \quad (1)$$

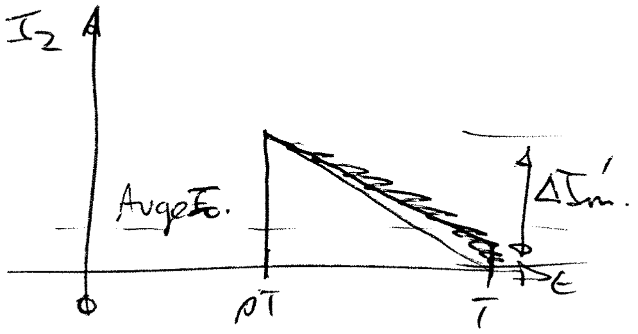
$$T_1 \text{ off: } -\frac{N_1 V_o}{N_2} = -\frac{L_m \Delta I_m}{(1-\rho)T}. \quad (2)$$

$$\Rightarrow (2) \div (1) \text{ is: } \frac{V_o N_1}{N_2 V_{DC}} = \frac{\rho}{1-\rho}$$

$$\Rightarrow V_o = V_{DC} \frac{N_2}{N_1} \frac{\rho}{1-\rho} \quad 6$$

Average $I_o = 0.4A$.

Waveforms:



$$\text{Avge}I_o = (1-\rho)\frac{\Delta I_m'}{2} = 0.4$$

$$\rho = 0.3 \Rightarrow \Delta I_m' = \frac{0.4 \times 2}{0.7} = \frac{0.8}{0.7} A.$$

$$V_o = V_{DC} \frac{N_2}{N_1} \frac{\rho}{1-\rho}$$

$$\Rightarrow 400 = 48\left(\frac{N_2}{N_1}\right)\left(\frac{0.3}{0.7}\right) \Rightarrow \frac{N_2}{N_1} = \frac{400 \times 0.7}{48 \times 0.3} = 19.444, \text{ say } 20.$$

$$\Rightarrow \Delta I_m \text{ on primary side} = \frac{0.8 \times 20}{0.7} = 22.9A$$

T=10e-6 secs (from f = 100kHz)

$$\Rightarrow V_{DC} = \frac{L_m 22.9}{0.3 \times 10e\text{-}6} \Rightarrow L_m = \frac{48 \times 0.3 \times 10e\text{-}6}{22.9} = 6.3\mu H \quad 4$$

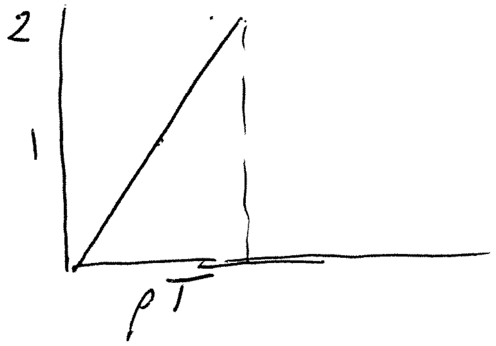
3 cont   assume ~~capacitor~~ C ~~is~~ [illegible] provides ideal ~~sufficient~~ smoothing under all conditions

Energy in during $V = L\frac{di}{dt}$.

$\frac{1}{2} I_o$ means $\frac{1}{2}$ power. $\Rightarrow \frac{1}{2}$ energy.

$$\text{Energy} = \int VI\,dt. = V\int I\,dt \text{ here.}$$

$$= V_{DC} \cancel{\times} 2\rho T$$



~~The~~ $V = L\frac{di}{dt_{\rho T}}$

$I = \frac{1}{L}\int_0 V dt.$

$\cancel{= \frac{1}{2} I \frac{t}{\rho T}}$

$$\Delta I_o = \frac{1}{L} V_{DC}\, \rho T$$

$$\text{Energy} = \frac{1}{2} V_{DC}.\, \rho T \times \frac{1}{L} V_{DC}\, \rho T = \frac{1}{2} V_{DC}^2 . \frac{1}{L} \rho^2 T^2$$

$V_{DC} \cdot L, T$ are. fixed

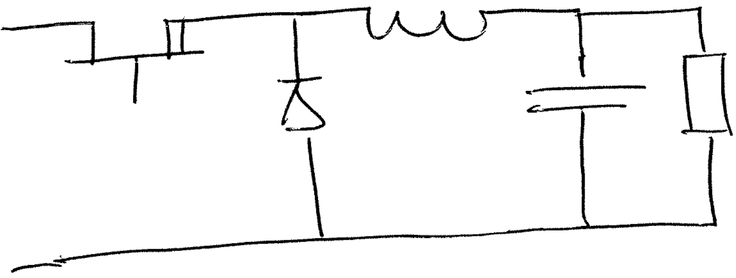
$\frac{1}{2}$ Energy $\rho_2^2 = \frac{\rho_1^2}{2} = \frac{0.3^2}{2}$

$$\rho_2 = \frac{0.3}{\sqrt{2}} = \underline{\underline{0.212}} \quad 4$$

~~What is the conduction time of the diode under these conditions~~

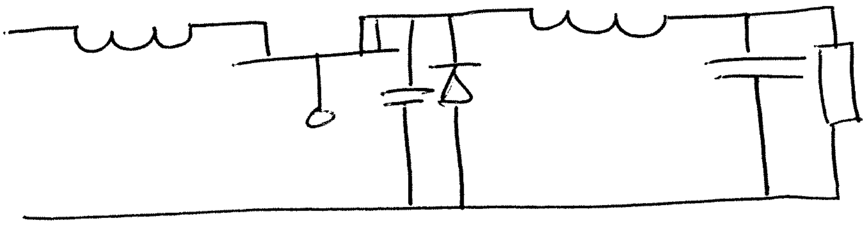
Comment on the requirements for C under these conditions.

4

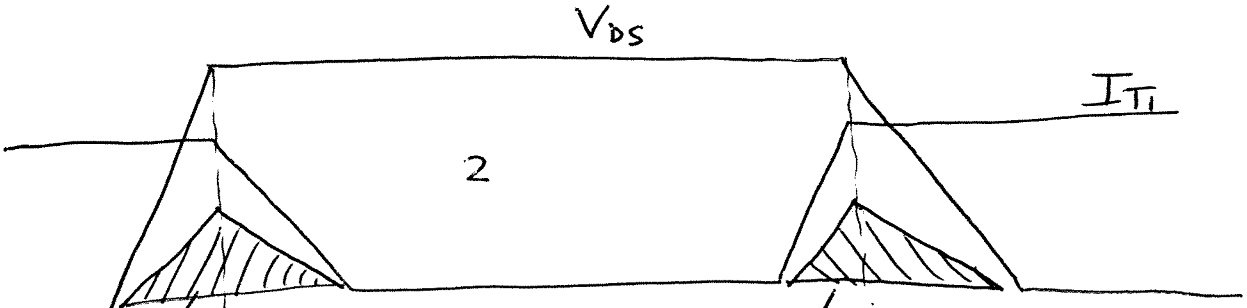


T	D
1	1
1	0
0	1
0	0

diode recovery.



a/ L and C are small for effective filtering and a fast response due to a high 'sampling' rate. 2



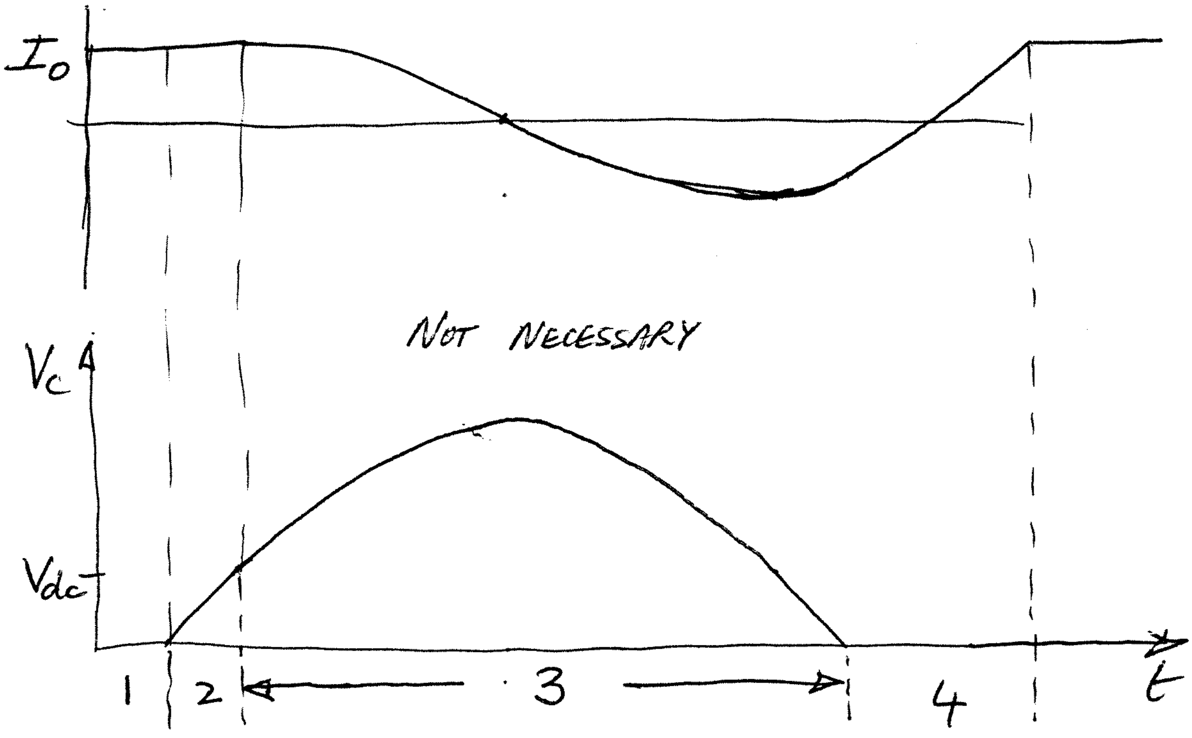
Power losses = Energy loss × freq. + on-state losses 2

4(b) (cont)

States.	(D₁)	T₁	D	
	~~0~~	~~0~~	~~1~~	~~Freewheeling.~~
	~~0~~	~~1~~	~~1~~	~~Current build up~~
	~~0~~	~~1~~	~~0~~	~~$I_L > I_{Lf}$ (resonate)~~
	~~1~~	~~0~~	~~0~~	~~I_L reverses.~~

States.

	(D₁)	T₁	D	
(1)	0	1	0	MOSFET ON
(2)	0	0	0	" OFF / L_f current is in C (charges)
(3)	0	0	1	C & L resonate (voltage on C grows) and comes back again!
Diode	1	0	1	$V_c=0$ Diode in T₁ conducts and T₁ turned on! Constant $\frac{dI_L}{dt}$ bringing I_L up from -ve value.
(4)	0	1	0	



4(b) MOSFET ON, DIODE OFF → Usual. Output pulse.

MOSFET OFF, DIODE OFF → C charges.

Not usually possible

MOSFET OFF, DIODE ON → Usual Freewheeling

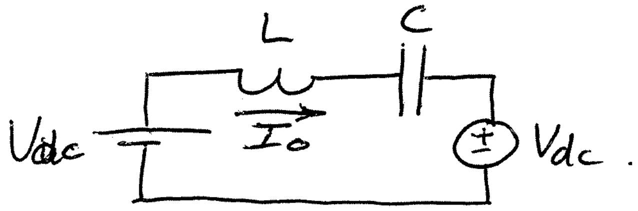
MOSFET ON, DIODE ON → Usual Diode recovery*

4

* except the inductance is higher than usual, which is good for diode recovery.

For each state in turn, see attached table and waveforms.

The initial voltage on C can be ignored as the Laplace version is



So max $\hat{V}_c = I_0 Z_0 + V_{dc}$. 4 (max switch voltage too).

Last Bit

Notice it is resonating the whole time the diode D_F is conducting. This is the $(1-PT)$ time for the (SMPS) Step down converter. So this time is fixed by the resonance. So the range of P must be set (by the requirements), the basic frequency set and then $1-PT$ is known.