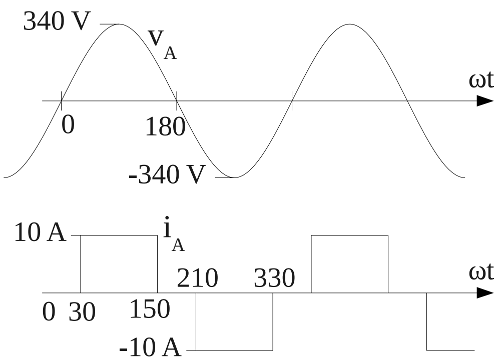
1. a) Shorter on-time for switches make the inductor currents have less time to build up. The maximum value of the generated magnetic flux is therefore less, and the physical size can thus be reduced.
   b) The frequency of the driving voltage controls the speed of the synchronous motor.
   c) Yes, example of this is that the fundamental of a square wave is 1.27 times the peak value.
   d) IGBT = Insulated Gate Bipolar Transistor
   e) The Cúk converter generates a negative output voltage.

2. a)



   b) The pulse shape of $i_A(t)$ is odd and half-wave.

1st harmonic (also known as the fundamental, h=1):

$a_1 = 0$

$$b_1 = \frac{4}{\pi}\int_0^{\frac{\pi}{2}} f(t)\sin(h\omega t)\,d(\omega t) = \frac{4}{\pi}\int_{\frac{\pi}{6}}^{\frac{\pi}{2}} 10\cdot\sin(\omega t)\,d(\omega t) = \frac{4\cdot 10}{\pi}\int_{\frac{\pi}{6}}^{\frac{\pi}{2}} \sin(\omega t)\,d\omega t =$$

$$= \frac{4\cdot 10}{\pi}\left[-\cos(\omega t)\right]_{\pi/6}^{\pi/2} = \frac{4\cdot 10}{\pi}\cdot\frac{\sqrt{3}}{2} = 11\ A$$

2nd harmonic (h=2):

$a_2 = 0\,;\, b_2 = 0\,;\,$ 1st harmonic amplitude $= 0$ V

3rd harmonic (h=3) (not really part of the question):

$a_3 = 0$

$$b_3 = \frac{4}{\pi}\int_0^{\frac{\pi}{2}} f(t)\sin(3\omega t)\,d(\omega t) = \frac{4}{\pi}\int_{\frac{\pi}{6}}^{\frac{\pi}{2}} 10\sin(3\omega t)\,d(\omega t) = \frac{4\cdot 10}{\pi\cdot 3}\int_{\frac{3\cdot\pi}{6}}^{\frac{3\cdot\pi}{2}} \sin(\omega t)\,d(\omega t) =$$

$$= \frac{4\cdot 10}{3\pi}\left[-\cos(\omega t)\right]_{\frac{\pi}{2}}^{\frac{3\pi}{2}} = 0$$

The 1st harmonic (fundamental) = 11 A, the 2nd harmonic = 0A.

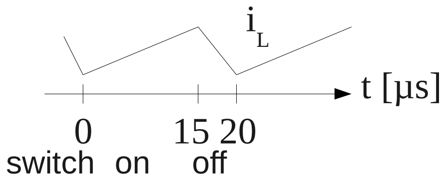
3. a) Efficiency $\eta = P_{out} / P_{in}$ = (250 * 6) / (400 * 4) = 1500 / 1600 = 93.75 %

b) Apparent output power is 250 * 6 A, maximum switch current = 6A (simplified assumption), maximim switch voltage $=\sqrt{(2)}\cdot 400\text{V}$, 4 switches. Switch utilization ratio = apparent output power / total switching capability $=\dfrac{250\cdot 6}{4\cdot\sqrt{(2)}\cdot 400\cdot 6}=11\%$

c) Total power loss equal to 1600 – 1500 = 100 W. That flows from the heat sink to the ambient. Heat sink to ambient thermal resistance = 0.8 C/W => increase of heat sink temperature by 0.8*100 = 80 C. The heat sink will then have a temperature of 50+80=130 C. Each thyristor dissipates 100/4 = 25 W. The junktion to heatsink thermal resistance = 2 C/W gives an increase of 2*25=50 C between heat sink and junktion. Junktion temperature is then 130 + 50 = 180 C.

4. a) $v_O=\dfrac{v_d}{1-D}=\dfrac{12}{1-0.75}=\dfrac{12}{0.25}=48\text{V}$

b)



c) R = 80 Ω, v_o = 48V => I_o = 48/80 = 0.6 A. While the switch on is the voltage across L v_L = 12V. Current increase during that time is $\dfrac{v_L\cdot T_{sw}\cdot D}{L}=\dfrac{12\cdot 0.75}{50\cdot 10^3\cdot 50\cdot 10^{-6}}=3.6\text{A}$

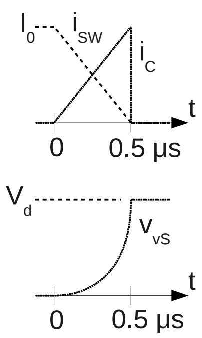
Power in should equal power out. P_{out} = 0.6*48, P_{in} = 12*I_{in} => $I_{in.avg}=\dfrac{0.6\cdot 48}{12}=2.4\text{A}$

Input current is only flowing during T_{on} , and is triangle shaped =>

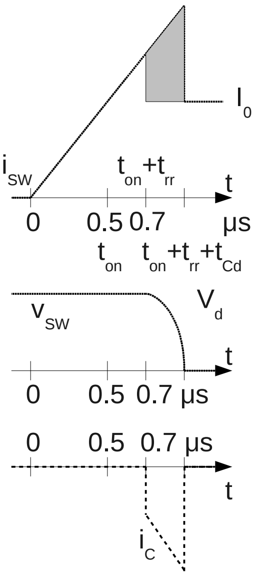
$I_{in.avg}=\dfrac{(I_{in.low}+I_{in.high})\cdot 0.75}{2}$ => Combine equations => $I_{in.high}=\dfrac{\dfrac{I_{in.avg}\cdot 2}{0.75}+3.6}{2}=5\text{A}$

This also gives I_{low} = 1.4 A.

5. a)



V_{SW} increase quadratically form 0 to V_d after 0.5 µs.



b) i_{SW} increase linearly for 0.5 us reaching I_0. The i_{SW} increase continuous for another 0.2 us due to D reverse recovery. Finally is the capacitor discharged while the switch current is still increasing. Once C is discharged the i_{SW} current is back to I_0. v_{sw} does not start to decrease until the capacitor starts to discharge after $t_{on}+t_{rr}$.

c) Calculate charge stored in C. Linearly increasing current at switch turn-off charges C.

Should charge to 380V after 0.5 us, where peak current is 10 A.

$$i_C(t)=\begin{Bmatrix} \dfrac{I_0 \cdot t}{t_{on}} & 0<t<t_{on} & (t_{on}=0.5\cdot 10^{-6}) \\ 0 & \text{otherwise} & \end{Bmatrix}$$

$$Q_C=\int_0^{t_{on}} i_C(t)\,dt=\left[\frac{I_0\cdot t^2}{2\cdot t_{on}}\right]_0^{t_{on}}=\frac{I_0\cdot t_{on}^2}{2\,t_{on}}=\frac{I_0\cdot t_{on}}{2}$$

$$v_C=\frac{Q}{C} \rightarrow C=\frac{Q}{v_C}=\frac{I_0\cdot 0.5\cdot 10^{-6}}{2\cdot V_d}=\frac{10\cdot 0.5\cdot 10^{-6}}{2\cdot 380}=6.6\,nF$$

At switch turn-on is i_{SW} increasing to I_0 after t_{on}, then further increase during t_{rr}. Then is C discharged while i_{SW} still increases during t_{Cd}. The current through the capacitance will be zero until $t_{on}+t_{rr}$ when it makes a step increase, then increase linearly, and drop back to zero at $t_{on}+t_{rr}+t_{Cd}$.

$$i_C(t) = \begin{Bmatrix} 0 & t < t_{on} + t_{rr} \\ I_0\left(1 + \frac{t_{rr} + t}{t_{on}}\right) & t_{on} + t_{rr} < t < t_{on} + t_{rr} + t_{Cd} \\ 0 & t > t_{on} + t_{rr} + t_{Cd} \end{Bmatrix}$$

$$Q_C = \int_{t_{on}+t_{rr}}^{t_{on}+t_{rr}+t_{Cd}} i_C(t)\,dt = I_0\left(\frac{t_{on} + t_{rr} + t_{Cd}}{2t_{on}}\right)(t_{on} + t_{rr} + t_{Cd}) - I_0\left(\frac{t_{on} + t_{rr}}{2t_{on}}\right)(t_{on} + t_{rr}) - I_0 t_{Cd}$$

Charge and discharge equal

$$\frac{I_0 \cdot t_{on}}{2} = I_0 \left\{ \left(\frac{t_{on} + t_{rr} + t_{Cd}}{2t_{on}}\right)(t_{on} + t_{rr} + t_{Cd}) - \left(\frac{t_{on} + t_{rr}}{2t_{on}}\right)(t_{on} + t_{rr}) - t_{Cd} \right\}$$

$$1 = \left(1 + \frac{t_{rr}}{t_{on}} + \frac{t_{Cd}}{t_{on}}\right)^2 - \left(1 + \frac{t_{rr}}{t_{on}}\right)^2 - 2\frac{t_{Cd}}{t_{on}}$$

$$t_{Cd} = \sqrt{t_{on}^2 + t_{rr}^2} - t_{rr}$$

$$i_{\mathrm{SW,peak}} = I_0 \frac{t_{on} + t_{rr} + t_{Cd}}{t_{on}} = I_0 \frac{t_{on} + t_{rr} + \sqrt{t_{on}^2 + t_{rr}^2} - t_{rr}}{t_{on}} = \frac{10 \cdot (0.5 + \sqrt{0.5^2 + 0.2^2}) \cdot 10^{-6}}{0.5 \cdot 10^{-6}} = 20.77\,A$$