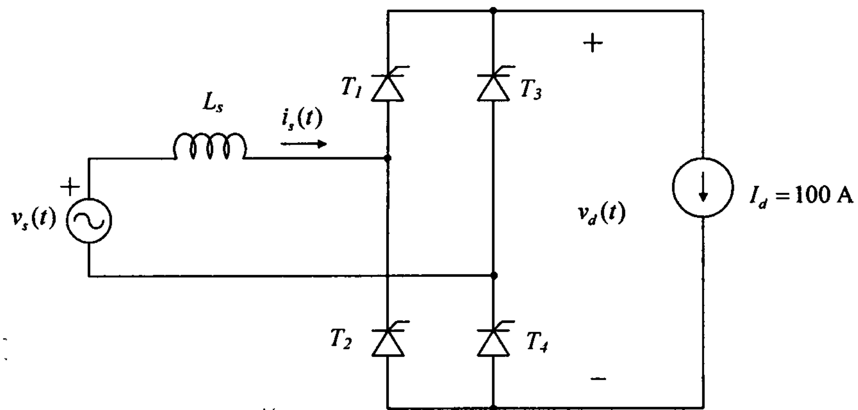
Introduction to Power Electronics * Midterm II * December 18, 2010

Student name: SOLUTIONS Number:

P1 (30) The circuit shown below is a single-phase full-bridge phase controlled rectifier supplying a highly inductive load. The load is represented by a constant DC current source. The rectifier input voltage is constant and equal to $v_s = \sqrt{2}\,220 \sin \omega t$ V and $I_d = 100$ A.

a) Plot the waveforms of v_d for the delay angle of $\alpha = 60°$ and $\alpha = 165°$, assuming Ls=0.
b) Calculate the source power factor for $\alpha = 60°$, $\alpha = 90°$ and $\alpha = 165°$, assuming Ls=0.
c) Calculate the active and reactive powers supplied by the source for each α case, assuming Ls=0.
d) Plot the waveform of i_s for the delay angle of $\alpha = 60°$ if Ls=1.2 mH. Note: use the third graph on the next page for your plotting.
e) Calculate the source power factor for the case in part (d). Note: You are allowed to approximating your answer by making reasonable assumptions.



b) $pf = k_d \cdot k_p = \frac{I_{s1}}{I_s} \cdot \cos\alpha$

k_d: distortion factor; k_p: displacement factor

$pf = (0.9) \cdot \cos\alpha$

α is the phase shift between voltage and current.

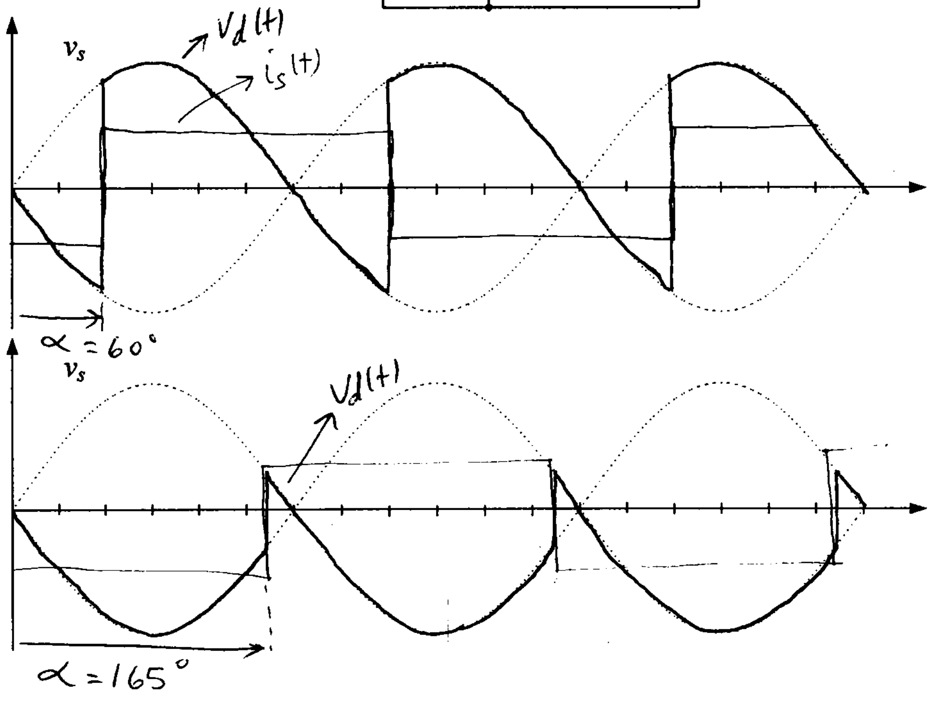
$pf = 0.9 \cos 60 = 0.45$ when $\alpha = 60°$

$pf = 0.9 \cos 90° = 0$ when $\alpha = 90°$

$pf = 0.9 \cos(165°) = -0.8693$ when $\alpha = 165°$

leading power factor

a)



c) $S_S = V_S \cdot I_S = 220 \cdot 100 = 22000$ VA this is always constant.

when $\alpha = 60°$ $P_s = 9.9$ kW $Q_s = 19.65$ kVar.

when $\alpha = 90°$ $P_s = 0$ $Q_s = 22$ kVar

when $\alpha = 165°$ $P_s = -19.124$ kW $Q_s = 10.875$ kVar

source absorbs active power

P2 (40): A buck (down converter) converter is needed for a military application requiring a tightly regulated dc voltage. The following specifications are given for the converter:

The average input voltage:	$V_d = 112$ V
The average output voltage:	$V_o = 28$ V
The output power:	$P_o = 560$ W
The peak-to-peak ripple at the inductor current:	$\Delta I_L \le 5$ A
The peak-to-peak ripple at the output voltage:	$\Delta V_o \le 0.4\%$ of V_o
The switching frequency:	$f_s = 50$ kHz $= 20\ \mu s$

Assume that the converter is operating in periodic steady-state and in continuous current mode (CCM) and all the components are ideal.

a) Determine the values of D, L, and C. And also the type of switches.

b) Draw the schematic of the converter.

c) Plot the waveforms of the inductor current, the converter input current, and the capacitor current. The waveforms must be plotted with the numerical values.

d) Plot the same waveforms if we assume that the inductor is infinitely large.

a) $D = \frac{28}{112} = 0.25 \quad (25\%)$

$I_L = I_o = \frac{P_o}{V_o} = \frac{560}{28}$

$L \geq \frac{(V_d - V_o)D}{\Delta I_L \cdot f_s} = \frac{(112-28)(0.25)}{5 \cdot (50000)} = 84\ \mu H$

$I_L = 20$ A

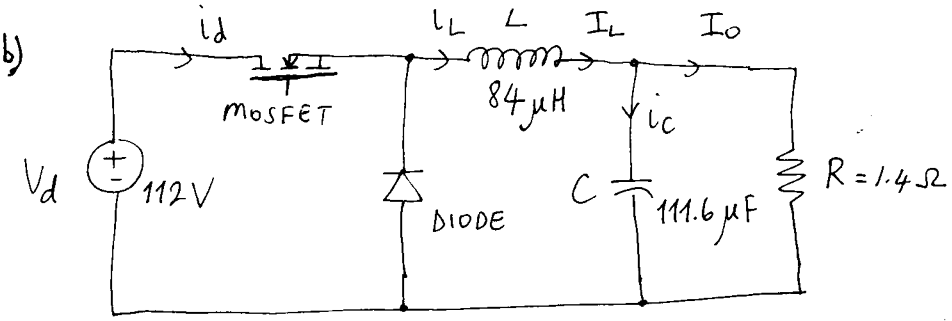
$C \geq \frac{\Delta I_L}{8\Delta V_o f_s} = \frac{5}{8(0.004 \times 28)50000} = 111.6\ \mu F$

$\Delta I_L = 5$ A

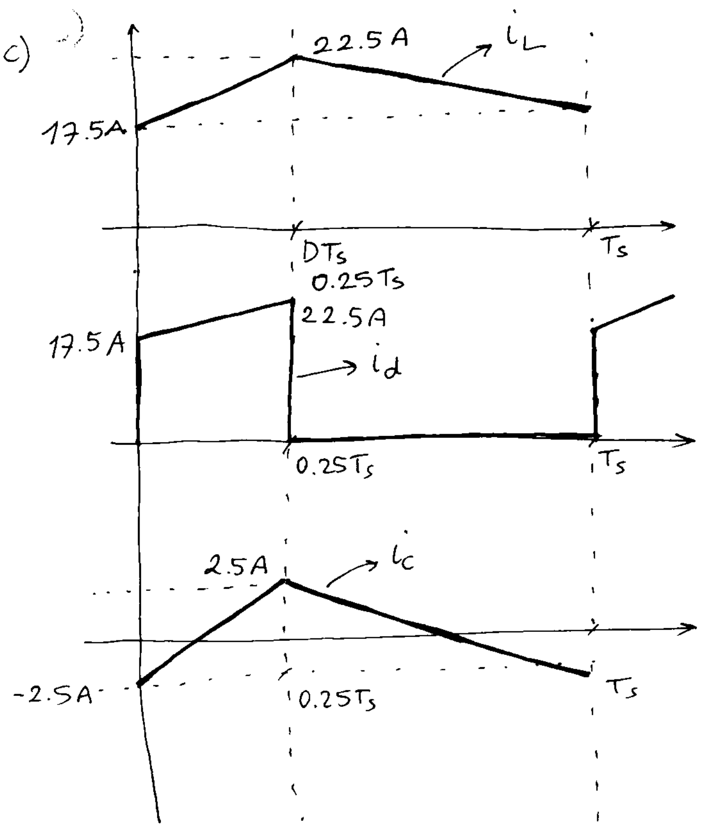
$I_{Lmax} = 20 + \frac{5}{2} = 22.5$ A

$I_{Lmin} = 20 - \frac{5}{2} = 17.5$ A

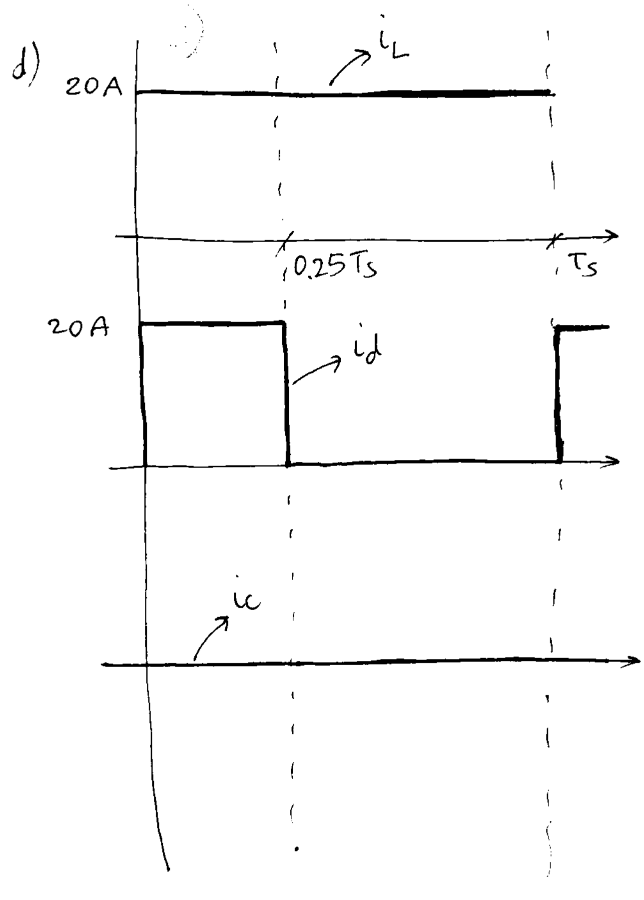
b)



c)



d)



d) $V_L = L\frac{di_L}{dt}$ $\quad di_L = \frac{V_L}{L}.dt$ $\quad \Delta i_s(t) = \frac{\sqrt{2}\,220 \sin(wt)\; d(wt)}{wL_s}$

$$\int_{i_s(0)}^{i_s(u)} di_s(t) = \frac{\sqrt{2}.220}{wL_s}\int_0^u \sin(wt)\,d(wt)$$

$$I_d + I_d = \frac{\sqrt{2}.220}{wL_s}(1-\cos u)$$

$$\frac{2wL_sI_d}{\sqrt{2}.220} = 1-\cos u$$

$$\cos u = 1 - \frac{2wL_sI_d}{\sqrt{2}.220}$$

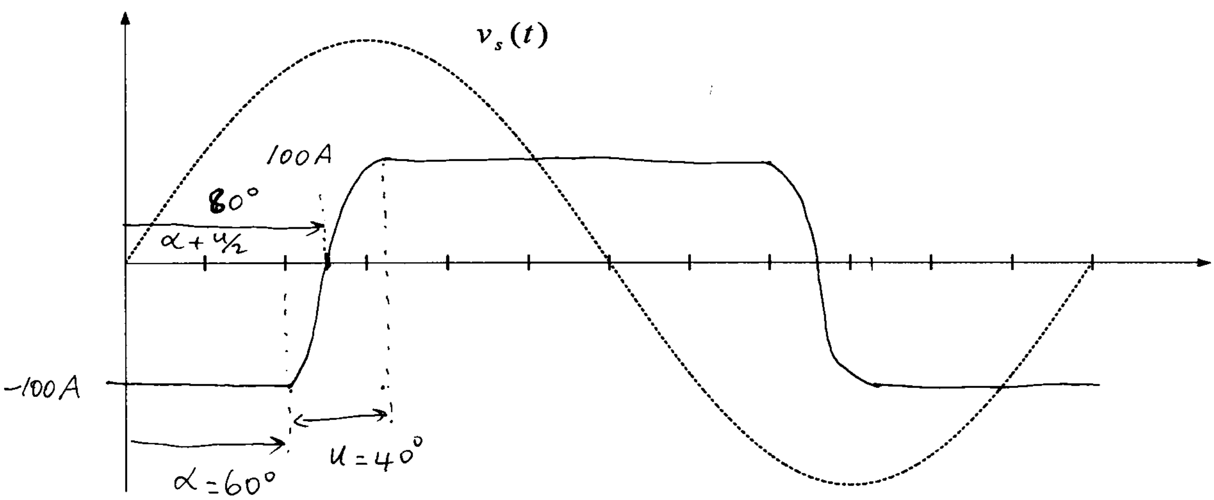
$$u = \cos^{-1}\left[1 - \frac{2wL_sI_d}{\sqrt{2}.220}\right]$$

$$u = \cos^{-1}\left(1 - \frac{2(314.16)\,1.2\times10^{-3}\times100}{\sqrt{2}\,(220)}\right)$$

$$u = \cos^{-1}(1-0.24234)$$

$$u = \cos^{-1}(0.75766)$$

$$u = 40^\circ$$



e) $pf \cong 0.9\cos(80^\circ)$ $\quad\alpha$ is 60°, but there is extra phase shift of 20° due to L_s.

$pf \cong 0.1563$

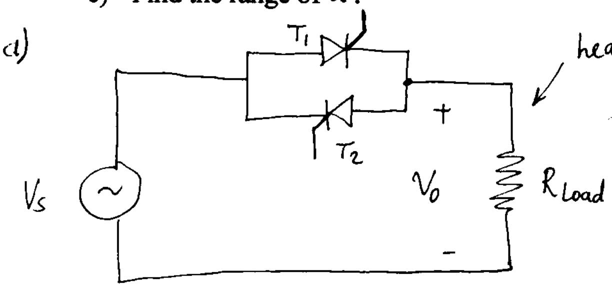
assuming 10% reduction in current harmonics $\quad k_d = \frac{I_{s1}}{I_s} = \frac{I_{s1}}{\text{a little lower } I_s}$

$pf \cong 0.95\cos(80^\circ) \cong 0.165$

P3 (30): We want to control the temperature of a room at 20°. The heat in the room will be maintained by a resistive heater. The room temperature is maintained at 20° if the power that goes to the heater is kept constant at 2000 W. The heater will be connected to the single-phase ac utility source available in the room. But the source voltage is always changing between 200 V and 260 V. This means that the temperature of the room will be continuously changing as the source voltage changes if there is no regulation of power. We have learned in the class that an ac chopper can be used to solve this kind of problems. The ac chopper can keep the room temperature at 20° if the power that is supplied to the heater is kept constant at 2000 W by properly controlling the switches in the circuit. When the voltage at the source is equal to $v_s(t) = \sqrt{2}.220\sin(2\pi 50t)$ volt, which is the nominal utility voltage, the heater draws 4840 W if it is directly connected to the source (it means that when no ac chopper is used).

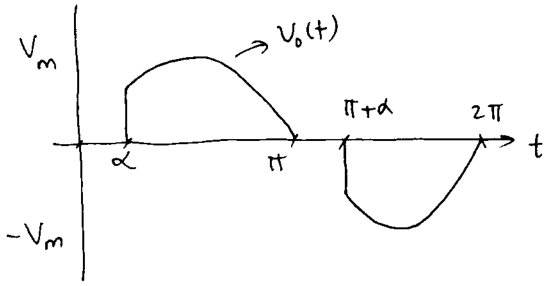
a) Draw the circuit schematic of the ac chopper.
b) Explain the elements used in the ac chopper.
c) Explain how the output power is controlled and derive the equation for the control angle α.
d) Find the control angle α when source voltage is 200 V.
e) Find the range of α.

a)



b) There are two thyristors connected back-to-back. Also a controller responsible from generating the proper triggering pulses to the thyristors.

c) The output power is equal to $P_o = \frac{V_o^2}{R}$. R is constant; so, controlling the RMS of V_o controls the output power.



$$V_o = \sqrt{\frac{1}{\pi}\int_\alpha^\pi V_m^2 \sin^2(wt)\, d(wt)}$$

$$V_o = \left\{ \frac{V_m^2}{2\pi}\left[\int_\alpha^\pi d(wt) + \int_\alpha^\pi \cos(2wt)\, d(wt)\right]\right\}^{1/2}$$

$$V_o = \left\{ \frac{V_m^2}{2\pi}\left[\pi-\alpha + \frac{\sin 2\alpha}{2}\right]\right\}^{1/2}$$

$$V_o = V_m\sqrt{\frac{1}{2\pi}\left(\pi-\alpha+\frac{\sin 2\alpha}{2}\right)}$$

d) The power at the output must be kept constant at 2000 W. So, let's first determine the resistance of the heater.

$$\frac{220^2}{R} = 4840 \qquad R = \frac{220^2}{4840} = 10\Omega$$

when $V_s = 200$ V

$$\frac{V_o^2}{10} = 2000 \qquad V_o^2 = 20000$$

Then, $\frac{V_m^2}{2\pi}\cdot\left(\pi-\alpha+\frac{\sin 2\alpha}{2}\right) = 20000$

where $V_m = \sqrt{2}.200$

Then $\frac{2(200)^2}{2\pi}\left(\pi-\alpha+\frac{\sin 2\alpha}{2}\right) = 20000$

$$\pi-\alpha+\frac{\sin 2\alpha}{2} = 1.5708$$

$$-2\alpha + \sin 2\alpha = -3.1416$$

$$\alpha = \frac{\pi}{2} = 90^\circ$$

e) when $V_s = 260$ V

$$-2\alpha + \sin 2\alpha = -4.4242$$

$\alpha = 110^\circ$

α	
0.5π	-3.1416
0.6π	-4.36
0.61π	-4.47

$90^\circ \leq \alpha \leq 110^\circ$