ECE 483/583 POWER ELECTRONICS

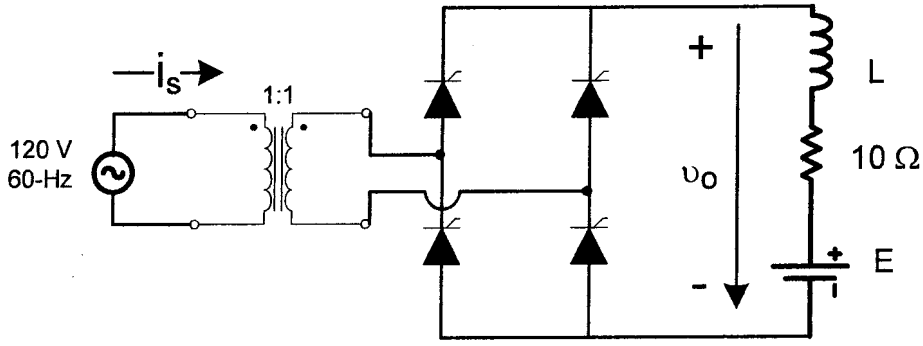
EXAM 1 (Closed books and notes, cheat sheet)

Problem 1 (50 points, assesses DO7,11): Consider the thyristor rectifier below.

a) E=0 V and L=0 H. Draw the output voltage, υ_o and the input current i_s, if the firing delay angle $\alpha=0°$. Calculate the average value of υ_o. Show the key values on the graph (10 points).

b) E=0 V and L=0 H. Draw the output voltage, υ_o and the input current i_s, if the firing delay angle $\alpha=90°$. Calculate the average value of υ_o. Show the key values on the graph (10 points).

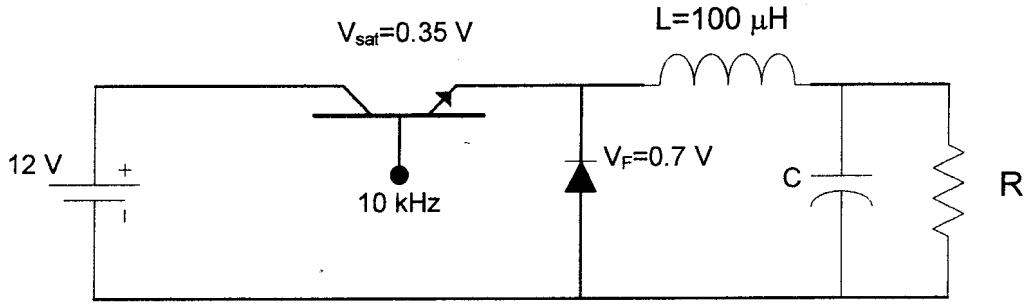
c) E=50 V and L=∞. Draw the output voltage, υ_o and the input current i_s, if the firing delay angle $\alpha=30°$. Calculate the average value of υ_o. Show the key values on the graph. Then find,
the rms value of i_s,
the rms value of the fundamental (60-Hz) component of i_s,
the rms of the 3rd and 5th harmonics and the harmonic factor of i_s,
also calculate the displacement factor, power factor and the input real and reactive powers (30 points).



Problem 2 (50 points, assesses DO7,8): Consider the buck regulator below. The desired output voltage is 9 V. The maximum output current is 8 A.

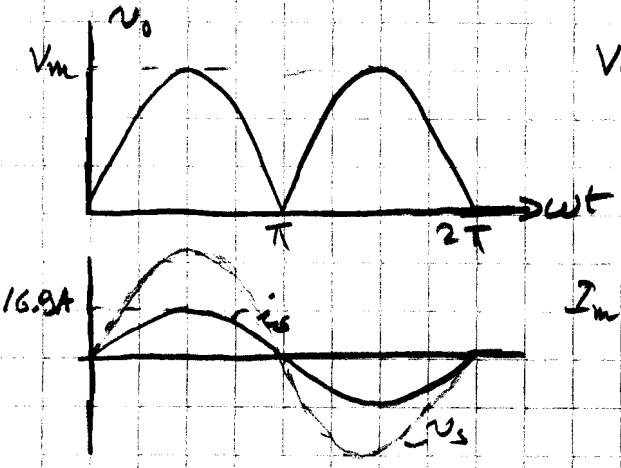
a. Find the average, rms and peak values of the switch current.
b. Find the value of the output capacitor to limit the output ripple to ±1 V.
c. Find the efficiency of the converter.
d. If the minimum load current is 1 A, what is the critical value of the output inductor to maintain continuous conduction?

Provide proper figures and waveform plots to demonstrate your calculations.



SOLUTIONS

P1.a : $\alpha = 0$, $E = 0\,V$, $L = 0\,H$ (purely resistive load)

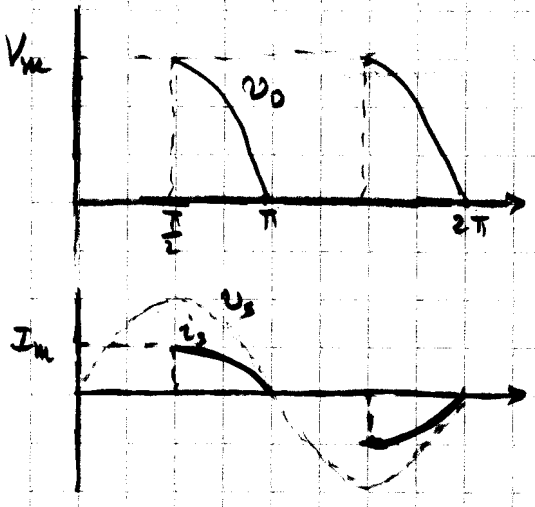


$V_m = \sqrt{2} \times 120 = 169.7\,V$

$V_{o,av} = \frac{2}{\pi} V_m = \underline{108.03\,V}$

$I_m = \frac{V_m}{R} = \underline{16.97\,A}$

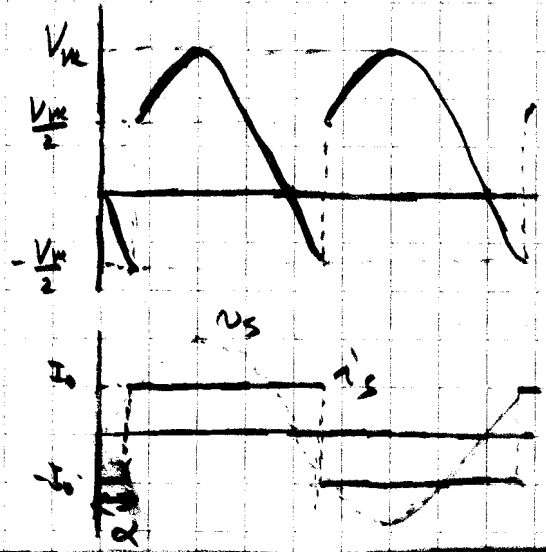
1.b : $\alpha = 90°$, $E = 0\,V$, $L = 0\,H$ (purely resistive load) Discontinuous cond.



$V_{o,av} = \frac{V_m}{\pi}(1 + \cos\alpha) = \frac{V_m}{\pi} = \underline{54.02\,V}$

$I_m = \frac{V_m}{R} = \underline{16.97\,A}$

1.C : $\alpha = 30°$, $E = 50\,V$, $L = \infty$ (ripple free) Continuous cond.



$V_{o,av} = \frac{2V_m}{\pi}\cos\alpha = \underline{93.56\,V}$

$I_{o,av} = \frac{V_{o,av} - E}{R} = \underline{4.35\,A}$

$P_{in} = V_s I_{s1} \cos\alpha$
$= \underline{407.37\,W}$
$Q_{in} = V_s I_{s1} \sin\alpha$
$= \underline{235.2\,VAR}$

$I_{s,RMS} = I_o = \underline{4.35\,A}$

$I_{s1,RMS} = \frac{2\sqrt{2}}{\pi} I_o = \underline{3.92\,A}$

$I_{s3,RMS} = \frac{2\sqrt{2}}{3\pi} I_o = \frac{I_{s1,RMS}}{3} = 1.31\,A$

$I_{s5,RMS} = I_{s1}/5 = 0.784\,A$

$HF = \frac{\sqrt{I_s^2 - I_{s1}^2}}{I_{s1}} = \underline{48.1\%}$

$\cos\alpha = 0.866 = DF$ (Lag)

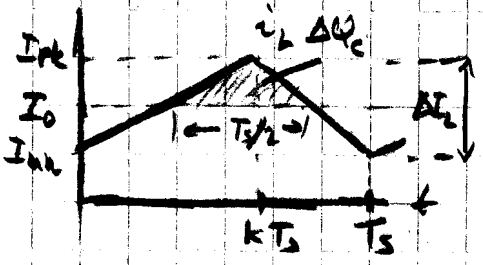
$Pf = \frac{V_s I_{s1} \cos\alpha}{V_s I_s} = \underline{0.78}$ Lag

a. Duty cycle: Assume continuous cond.

$v_{LON} = 12 - 0.35 - 9 = 2.65\,V$, $v_{LOP} = -0.7 - 9 = -9.7\,V$

$v_{LON} kT_s = |v_{LOP}|(1-k)T_s \Rightarrow 2.65k = 9.7(1-k) \Rightarrow \underline{k = 0.785}$

Inductor current



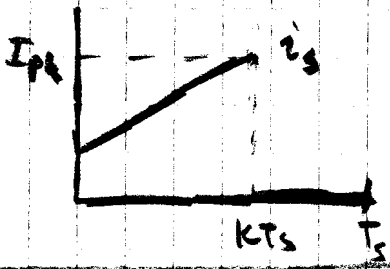
$I_{L,av} = I_o = 8\,A$ (at max. output current)

$\Delta I_L = \frac{v_{LON} kT_s}{L} = \frac{v_{LON} k}{L f_s} = \frac{2.65V \times 0.785}{100\mu H \times 10kHz} = \underline{2.08\,A}$.

Therefore

$I_{pk} = I_o + \frac{\Delta I_L}{2} = \underline{9.04\,A}$, peak switch current

$I_{min} = I_o - \frac{\Delta I_L}{2} = \underline{6.96\,A}$



$I_{s,av} = kI_{L,av} = \underline{6.28\,A}$

$I_{s,RMS} = \sqrt{k} \cdot I_{L,RMS}$, but $I_{L,RMS} \approx \sqrt{I_o^2 + \left(\frac{\Delta I_L}{2\sqrt{k}}\right)^2} = \underline{8.034A}$

(Also, $I_{L,RMS} \approx I_o$ acceptable)

And $I_{s,RMS} = \underline{7.12\,A}$

b. Capacitor charge:

$\Delta Q_c = \frac{1}{2}\left(\frac{\Delta I_L}{2}\right)\frac{T_s}{2} =$

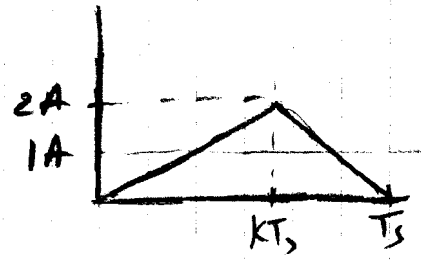
$= \frac{1}{8}\frac{\Delta I_L}{f_s} = 26\mu C$

and

$C \geq \frac{\Delta Q_c}{\Delta V_o} = \frac{26\mu C}{2V} = \underline{13\mu F}$ and $C_{min} = \underline{13\mu F}$

c. $P_{in} = V_{in} \times I_{s,av} = 12V \times 6.28A = 75.36A$, $P_{out} = 9 \times 8 = 72\,W$, or $\eta = 95\%$.

d. Duty cycle remains same, $k = 0.785$



In cont. cond. $I_{L,av} = I_o = 1A$. From the figure

$\Delta I_L = 2A$. But $\Delta I_L = \frac{v_{LON} kT_s}{L} \Rightarrow L = \frac{v_{LON} k}{\Delta I_L f_s}$

To sustain cont. cond

$L \geq \frac{v_{LON} k}{\Delta I_L f_s} = \frac{2.65 \times 0.785}{2 \times 10kHz} = \underline{104\,\mu H}$