Problem 1. One cycle of a periodic voltage waveform is shown below. What value of D yields an rms value of (0.2, 0.5, 0.3)V?

\[ V_{RMS} = \frac{1}{T} \int_0^T v^2(t) \, dt \]

\[ V_{RMS}^2 = (1)^2 D + (1)^2 D = 2D \]

\[ D = \frac{V_{RMS}^2}{2} \]

\[ D = \frac{(0.2)^2}{2} = 0.04 = 0.02 \]

Others. \( V_{RMS} = 0.17, \quad D = 0.245 \)

\( = 0.5, \quad D = 0.125 \)

\( = 0.3, \quad D = 0.045 \)

a. \( \neq 0.02 \)  
b. \( \neq 0.245 \)  
c. \( \neq 0.125 \)  
d. \( \neq 0.045 \)  
e. Other

Problem 2. A DBR serves a constant (60, 50, 20, 60)W computer load. The DBR’s 470\( \mu \)F capacitor voltage is practically constant at 160V. Suddenly, there is a power blackout. The capacitor voltage starts to drop, and when it reaches 100V, the computer trips off. Assuming constant load power, how long does it take for the computer to trip off?

Power balance, \( P = C \frac{V_{peak}^2 - V_{trip}^2}{2} = P \cdot t_{trip} \)

\[ t_{trip} = \frac{C \frac{V_{peak}^2 - V_{trip}^2}{2}}{P} = \frac{(470 \times 10^{-6}) (160^2 - 100^2)}{2 \times (60)} = 0.0611 \text{ sec} \]

Others \( P = 50W, \quad t_{trip} = 0.0733 \text{ sec} \)

\( 70 \) \( = 0.0524 \text{ sec} \)

\( 80 \) \( = 0.0458 \text{ sec} \)

a. \( \neq 61.1 \text{ msec} \)  
b. \( \neq 73.3 \text{ msec} \)  
c. \( \neq 52.4 \text{ msec} \)  
d. \( \neq 45.8 \text{ msec} \)  
e. Other
Problem 3. The circuit shown below is operating in periodic steady-state. One cycle of the current \( i(t) \) is shown. The load draws constant current. Determine the peak-to-peak ripple voltage on the 1000\( \mu \)F capacitor.

\[
\Delta V = \frac{1}{2} \left( I_p \cdot \frac{I_p}{2} \right) = \frac{T \cdot I_p}{8} = C \cdot \Delta V
\]

\[
\Delta V = \frac{\Delta Q}{C} = \frac{T \cdot I_p}{8C} = \frac{(0.001)(4)}{8(10^{-3})} = 0.5 V
\]

Others: 3A, 0.375V
7A, 0.875V
5A, 0.625V

- a. \( \approx 0.500V \)
- b. \( \approx 0.375V \)
- c. \( \approx 0.875V \)
- d. \( \approx 0.625V \)
- e. Other

Problem 4. The conventional firing circuit of a triac light dimmer is replaced with the one shown below. If \( V_{an} = 120\sqrt{2} \sin(120\pi t) \), and the diac has a 32V breakover voltage, what is the firing angle \( \alpha \)?

\[
\left( V_p \sin \alpha \right) \frac{R_2}{R_1 + R_2} = V_{BRK}
\]

\[
\sin \alpha = \frac{V_{\text{BRK}} (R_1 + R_2)}{V_p} = \frac{32}{120\sqrt{2}} \left( \frac{10 + 8}{8} \right)
\]

\[
\sin \alpha = 0.4241, \alpha = 25.1^\circ
\]

Others: \( R_2 = 7K \), \( \alpha = 27.3^\circ \)
6K\( \), \( = 30.2^\circ \)
5K\( \), \( = 34.5^\circ \)

- a. \( \approx 25.1^\circ \)
- b. \( \approx 27.3^\circ \)
- c. \( \approx 30.2^\circ \)
- d. \( \approx 34.5^\circ \)
- e. Other
Problem 5. A portion of Monday’s solar radiation data is shown below. The afternoon sky was so clear that diffuse horizontal radiation was practically negligible. Use the global horizontal \[ \text{component} \] together with sun and panel orientation, to estimate the incident solar power on our panels at \((1530, 1400, 1500, 1430)\) hours, in \(\text{W/m}^2\).

<table>
<thead>
<tr>
<th>Monday 20-Mar-06 Time</th>
<th>Global Horizontal (\text{W/m}^2)</th>
<th>Sun zenith angle</th>
<th>Cosine of Sun zenith angle</th>
<th>Incidence angle</th>
<th>Cosine of Incidence angle</th>
</tr>
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<tbody>
<tr>
<td>1200</td>
<td>859</td>
<td>32.5</td>
<td>0.843</td>
<td>21.7</td>
<td>0.929</td>
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<td>1215</td>
<td>872</td>
<td>31.7</td>
<td>0.851</td>
<td>18.9</td>
<td>0.946</td>
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<td>882</td>
<td>31.2</td>
<td>0.855</td>
<td>16.5</td>
<td>0.959</td>
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<tr>
<td>1245</td>
<td>885</td>
<td>31.1</td>
<td>0.856</td>
<td>14.6</td>
<td>0.968</td>
</tr>
<tr>
<td>1300</td>
<td>883</td>
<td>31.5</td>
<td>0.853</td>
<td>13.6</td>
<td>0.972</td>
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<tr>
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<td>879</td>
<td>32.2</td>
<td>0.846</td>
<td>13.4</td>
<td>0.973</td>
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<tr>
<td>1330</td>
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<td>33.3</td>
<td>0.836</td>
<td>14.3</td>
<td>0.973</td>
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<tr>
<td>1345</td>
<td>853</td>
<td>34.7</td>
<td>0.822</td>
<td>16.0</td>
<td>0.961</td>
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<td>1400</td>
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<td>18.3</td>
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<td>0.933</td>
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<td>0.759</td>
<td>24.0</td>
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<tr>
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<td>1500</td>
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<td>0.701</td>
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<td>0.862</td>
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<td>1515</td>
<td>691</td>
<td>48.2</td>
<td>0.667</td>
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<td>1530</td>
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<td>0.590</td>
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<tr>
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<td>560</td>
<td>56.7</td>
<td>0.548</td>
<td>44.3</td>
<td>0.716</td>
</tr>
</tbody>
</table>

Others: 1400 \(\rightarrow\) 987 \(\text{W/m}^2\), 1500 \(\rightarrow\) 894 \(\text{W/m}^2\), 1430 \(\rightarrow\) 950 \(\text{W/m}^2\)

\(a. \approx 821 \text{W/m}^2\) \(b. \approx 987 \text{W/m}^2\) \(c. \approx 882 \text{W/m}^2\) \(d. \approx 950 \text{W/m}^2\) \(e. \) Other

Problem 6. A buck converter operates at the following conditions: \((50, 40, 40, 10)\) \(\text{kHz}\), 100W, 40V input, 20V output. \(L = 100 \mu\text{H}\). Determine the \(\text{peak}\) value of the inductor current.

\[ \text{Switch closed,} \quad \frac{\text{d}i}{\text{d}t} = \frac{V_{\text{IN}} - V_{\text{OUT}}}{L} \]

For \(T/2 = 10 \mu\text{sec}\), \(\frac{\text{d}i}{\text{d}t} = \frac{V_{\text{IN}} - V_{\text{OUT}}}{L} = \frac{40 - 20}{100 \mu\text{H}} = 0.2 \text{A/\musec}\)

Thus \(I_{\text{peak}} = I_{\text{avg}} + \frac{\Delta I}{2} = 5 + \frac{0.2}{2} = 6 \text{A}\)

\(a. \approx 6.00 \text{A}\) \(b. \approx 6.67 \text{A}\) \(c. \approx 6.25 \text{A}\) \(d. \approx 5.71 \text{A}\) \(e. \) Other

Others: 30 kHz, \(T = 33.3 \mu\text{sec}\), \(T/2 = 16.67 \mu\text{sec}\), \(\Delta I = 3.33 \text{A}\), \(I_{\text{peak}} = 5 + \frac{3.33}{2} = 6.67 \text{A}\)
40 kHz, \(T = 25 \mu\text{sec}\), \(T/2 = 12.5 \mu\text{sec}\), \(\Delta I = 2.5 \text{A}\), \(I_{\text{peak}} = 5 + \frac{2.5}{2} = 6.25 \text{A}\)
70 kHz, \(T = 14.3 \mu\text{sec}\), \(T/2 = 7.14 \mu\text{sec}\), \(\Delta I = 1.928 \text{A}\), \(I_{\text{peak}} = 5 + \frac{1.928}{2} = 5.714 \text{A}\)
Problem 7. Consider the actual P-V curve for a solar panel. A boost converter is connected between the solar panel and a (0.50, 10.0) Ω load resistor. For the sun and panel orientation conditions represented by the P-V curve, what duty cycle D will draw maximum power from the solar panel?

![Panel Power versus Voltage](image)

\[
\text{Lossless, } \frac{V_{\text{LOAD}}^2}{R_{\text{LOAD}}} = P_{\text{MAX}}, \quad V_{\text{LOAD}}^2 = P_{\text{MAX}} R_{\text{LOAD}}.
\]

Also, \( V_{\text{LOAD}} = (\frac{1}{1-D})V_{\text{PANEL}} \), so

\[
V_{\text{LOAD}}^2 = (\frac{1}{1-D})^2 V_{\text{PANEL}}^2.
\]

So,

\[
P_{\text{MAX}} R_{\text{LOAD}} = (\frac{1}{1-D})^2 V_{\text{PANEL}}^2 \quad \text{and} \quad (1-D)^2 = \frac{V_{\text{PANEL}}^2}{P_{\text{MAX}} R_{\text{LOAD}}} \]

\[
(1-D) = \frac{V_{\text{PANEL}}}{\sqrt{P_{\text{MAX}} R_{\text{LOAD}}}}, \quad \text{so} \quad D = 1 - \frac{V_{\text{PANEL}}^2}{V_{\text{PANEL}}^2} = 1 - \frac{28}{\sqrt{(15)(60)}} = 0.663
\]

Others 0.52, D = 0.725
40.2, D = 0.587
150.2, D = 0.787

\[
\begin{array}{cccc}
a. & 0.66 & b. & 0.73 & c. & 0.59 & d. & 0.79 & e. & \text{Other} & \\
\end{array}
\]

\( V_{\text{LOAD}} = 83.1V, \quad P_{\text{LOAD}} = \frac{V_{\text{LOAD}}^2}{R} = 15W \) (OK)
Problem 1 (3 points). The input side of an optoisolator is turned on and off by a 12Vdc power supply. For proper turn-on, the opto requires 20mA @ 1.5V. To achieve this, what series resistance must be inserted between the opto and the power supply?

\[ R = \frac{12V - 1.5V}{0.020A} = 525 \Omega \]

- Version B: 15Vdc, R = 675Ω
- Version C: 9Vdc, R = 375Ω
- Version D: 18Vdc, R = 825Ω

a. 825Ω  b. 375Ω  c. 675Ω  d. 525Ω  e. Other

Problem 2 (3 points). A MOSFET's gate is a capacitor. Consider a case where a 12Vdc driver chip turns on a MOSFET through a 100Ω series resistor. When the driver output goes "high," VGS increases to 4Vdc in 0.2μsec. Compute the capacitance of the MOSFET's gate.

Hint - use charging expression \( v(t) = 12(1 - e^{-t/RC}) \).

\[ V_G = 12 \left[ 1 - e^{-\frac{t}{RC}} \right], \quad \frac{V_G}{12} = 1 - e^{-\frac{t}{RC}}, \quad e^{-\frac{t}{RC}} = 1 - \frac{V_G}{12}, \]

\[ \frac{-t}{RC} = \ln \left[ 1 - \frac{V_G}{12} \right], \quad RC = \frac{-t}{\ln \left[ 1 - \frac{V_G}{12} \right]}, \quad C = \frac{-t}{R \ln \left[ 1 - \frac{V_G}{12} \right]} \]

\[ C = \frac{-0.2 \times 10^{-6}}{100 \ln \left[ 1 - \frac{4}{12} \right]} = \frac{-0.2 \times 10^{-6}}{100 \ln (\frac{4}{12})} = 4.93 \text{nF} \]

- Version B: 0.4μsec, C = 9.86nF
- Version C: 0.1μsec, C = 2.47nF

a. 9.87nF  b. 2.47nF  c. 4.93nF  d. 14.8nF  e. Other
Problem 3 (3 points). The MOSFET firing circuit shown below is not exactly like the one you used in your inverter – I have changed the output stage and created a problem. What is the problem, and what will be its impact? Explain in two or three sentences.

![MOSFET Firing Circuit Diagram]

**Answer:**
The diode is reversed. This means that the MOSFET will turn on quickly through the 10Ω resistor, but it will turn off slowly through the 1200Ω resistor. This is opposite from what we want.

Problem 4 (3 points). Every capacitor has a current rating. Consider the 10μF, 50V bipolar high-frequency capacitor that you used in your inverter's output filter. This capacitor is used along with a 100μH inductor. Find the rms current in the capacitor for the following situation:

- No load attached to output Vac.
- The inverter's voltage (on the left side of the filter) has 25VRms of 60Hz, and 10V rms of 40kHz.
- No other frequencies are present.

Hint - the total squared rms current is the sum of squared individual rms harmonic currents.

**For 60Hz,**

\[ V = 25V, \quad I = \frac{j0.377a}{2655Ω}, \quad |I| = 0.0944A \]

**For 40kHz,**

\[ V = 10V, \quad I = j25.15Ω \quad -j0.398Ω, \quad |I| = 0.405A \]

\[ I_{rms} = \sqrt{(0.0944)^2 + (0.405)^2} = 0.416A \]

<table>
<thead>
<tr>
<th>a. 0.58-0.62A</th>
<th>b. 0.38-0.42A</th>
<th>c. 0.98-1.02A</th>
<th>d. 0.78-0.82A</th>
<th>e. Other</th>
</tr>
</thead>
</table>

**Version B:** V\(_{40k}\) = 20V
\[ |I_{40k}| = 0.810A, \quad I_{rms} = 0.815A \]

**Version C:** V\(_{40k}\) = 15V
\[ |I_{40k}| = 0.608, \quad I_{rms} = 0.615A \]

**Version D:** V\(_{40k}\) = 25V
\[ |I_{40k}| = 1.013A, \quad I_{rms} = 1.02A \]
Problem 5 (3 points). An unfiltered PWM inverter has a sinusoidal 60Hz $V_{\text{cont}}$ input. The inverter’s triangle wave frequency is 20kHz. The FFT of the inverter output shows a strong 40kHz cluster component that is 8.1 dB down from the 60Hz component. If $V_{dc} = 40V$, and $m_a = 0.8$, what is the rms value of the 40kHz cluster voltage in volts? (Note – do not use the $m_a$ table from the lab document).

\[
V_{60, \text{rms}} = m_a \frac{V_{dc}}{\sqrt{2}} = 0.8 \left( \frac{40}{\sqrt{2}} \right)
\]
\[
= 22.6 \text{ V}
\]

\[-8.1 \text{ dB} = 20 \log_{10} \left( \frac{V_{40K}}{V_{60}} \right) \]
\[
\log_{10} \left( \frac{V_{40K}}{V_{60}} \right) = -\frac{8.1}{20}
\]
\[
\frac{V_{40K}}{V_{60}} = 10^{-\frac{8.1}{20}} = 0.394
\]
\[
V_{40K} = (22.6)(0.394)
\]
\[
= 8.9 \text{ V}
\]
Problem 6 (3 points). When using your inverter as an audio amplifier, you tested it with a pure 1kHz sinusoidal input. Assume that the FFT of the amplifier output showed
- a 3kHz component whose magnitude is 0.040 of the 1kHz component.
- a 5kHz component whose magnitude is 0.025 of the 1kHz component.
- no other significant frequency components.
Compute the total harmonic distortion (THD) of the amplifier’s output voltage.

\[ THD_v = \sqrt{(0.040)^2 + (0.025)^2} = 0.0472 \]

**Version B**
\[ V_{5K} = 0.015 \]
\[ THD_v = 0.043 \]

**Version C**
\[ V_{5K} = 0.035 \]
\[ THD_v = 0.053 \]

**Version D**
\[ V_{5K} = 0.030 \]
\[ THD_v = 0.050 \]

a. 0.047  b. 0.053  c. 0.050  d. 0.043  e. Other ________________

Problem 7 (7a, 7b, and 7c form one problem). No justification is needed for your answer.

**Problem 7a** (1 point). You pay about $0.12 per kWh for retail electric energy. About how much does it cost electric utilities to produce wind energy (in $ per kWh)?

a. 0.11-0.14  b. 0.02-0.05  c. 0.08-0.11  d. 0.05-0.08  e. 0.14-0.17

**Problem 7b** (1 point). Roy Blackshear’s wind farm in west Texas has more than 100 wind turbines. What is the power rating (in MW) of each of his wind turbines?

a. 5.0  b. 1.5  c. 2.5  d. 0.5  e. 3.5

**Problem 7c** (1 point). Regarding our tour of the Fine Arts Building utility room, what is the approximate cost range of motor drives like the one we saw (in $ per horsepower)?

a. 500  b. 250  c. 100  d. 50  e. 750
Problem 1. Determine the rms value of the voltage waveform shown. B is a variable.

\[ V_{\text{rms}} = \text{Average value of the squared waveform.} \]

- For the first T/2 seconds, the average squared value has been shown to be \( (V_{\text{avg}})^2 + \frac{1}{12}(AV)^2 \), and for the triangle shown, this yields \( \left( \frac{3B}{2} \right)^2 + \frac{1}{12}(B)^2 = \frac{9B^2}{4} + \frac{B^2}{12} \)

\[ = B^2 \left( \frac{9}{4} + \frac{1}{12} \right) = B^2 \left( \frac{27+1}{12} \right) = B^2 \left( \frac{28}{12} \right) = B^2 \left( \frac{7}{3} \right) \]

- For \( \frac{T}{2} \leq t \leq T \), the average squared value is \( B^2 \).

Combining, \( V_{\text{rms}}^2 = \frac{1}{2} \left[ B^2 \left( \frac{7}{3} \right) \right] + \frac{1}{2} [B^2] = B^2 \left[ \frac{7}{6} + \frac{1}{2} \right] \)

\[ V_{\text{rms}}^2 = B^2 \left[ \frac{7+3}{6} \right] = B^2 \left[ \frac{10}{6} \right] = B^2 \left( \frac{5}{3} \right) \]

So \( V_{\text{rms}} = B \sqrt{\frac{5}{3}} \) V

1.291 B

(OK with sanity check)

Notes - Not much credit for answers outside the possible B-to-2B range, or for answers that have T in them.
Problem 2. Last Thursday was a brilliant solar day in Austin. A screen shot of our rotating shadowband pyranometer data is shown below. Graphically estimate the kWH that would have been produced by a horizontal solar panel having 1 m² of surface area and 14% efficiency.

A horizontal panel sees global horizontal (GH) Integrate the area under the GH curve, where each box is (200 W/m²) * (1 hr) = 0.200 kWH/m²
(32 whole boxes) plus (11 half boxes) plus (2 one-fourth boxes) = 32 + \frac{11}{2} + \frac{2}{4} = 32 + 5\frac{1}{2} + \frac{1}{2} = 38 boxes

38 boxes * 0.200 = 7.6 kWH/m²
Multiply by η = 0.14, yields 1.06 kWH

Notes - Not much credit for using the wrong curve. Answers off by a factor of W H to kWH, like 1000 kWH, should have been easily caught by students with panel experience.
Problem 3. Help me design a boost converter for a solar array that will be moved from ETC to ENS this year. The maximum power condition for the array is 1kW @ 64V. The boost converter will drive light bulbs at 120V, using a switching frequency of 50kHz.

(a) Determine the smallest input inductor (in μH) that limits the array's peak-to-peak ripple current to 1A at the maximum power condition.

(b) Neatly sketch the input inductor current, and determine its rms value.

\[ V_{\text{out}} = \frac{V_{\text{in}}}{1 - D} \]

When switch closed,

\[ L \frac{\Delta i}{dt} = V_{\text{in}}, \quad \frac{\Delta i}{dt} = \frac{V_{\text{in}}}{L} \]

\[ \Delta I = \frac{V_{\text{in}}}{L} \cdot DT = \frac{V_{\text{in}} D}{F} \text{ Amps} \]

Using \( V_{\text{out}} = \frac{V_{\text{in}}}{1 - D} \) → \( 1 - D = \frac{V_{\text{in}}}{V_{\text{out}}} \)

\[ D = 1 - \frac{V_{\text{in}}}{V_{\text{out}}} = 1 - \frac{64}{120} \]

\[ D = 0.467 \]

To find \( L_{\text{min}} \), rewrite \( \Delta I = \frac{V_{\text{in}} D}{F} \) ⇒ \( L_{\text{min}} = \frac{V_{\text{in}} D}{F \Delta I} \)

\[ L_{\text{min}} = \frac{64 \times 0.467}{50000 \times 1} = 59.8 \mu\text{H} \]

\[ L(t) \]

\[ 15.63 + \frac{1}{2} = 16.13 \text{A} \]

\[ \frac{1000W}{64V} = 15.63 \text{A} \]

\[ 15.63 - \frac{1}{2} = 15.13 \text{A} \]

\[ t = 0 \quad t = 9.34 \mu\text{s} \quad t = 20 \mu\text{s} \]

\[ I_{\text{rms}}^2 = \frac{(15.63)^2 + \frac{1}{12} (4)^2}{244.3 + \frac{0.08}{(\text{small})}} \]

So \( I_{\text{rms}} \approx 15.63 \text{A} \)
Problem 4. The output of your PWM inverter is connected to the same LC filter that you used in the lab. No load is attached to the filter output.

Consider a situation where the input to your inverter is a perfect 3kHz sine wave. Due to nonlinearities, your inverter output has the desired $V_{3\text{kHz}}$ component, but also a $V_{9\text{kHz}}$ (i.e., 3\textsuperscript{rd} harmonic) component. No other frequencies are present in the inverter's output. (No 4 kHz, etc.)

When you measure the THD\textsubscript{v} at the filter's output, you get a value of 0.01. What is the THD\textsubscript{v} at your inverter’s output?

Hint – you will need to use the magnitude of the output filter’s transfer function at 3kHz and 9kHz. Also, remember that THD = (rms value of harmonics) divided by (rms value of fundamental).

Here we have a fundamental (i.e., $V_{3\text{kHz}}$) and one harmonic ($V_{9\text{kHz}}$). With one harmonic present, then $THD = \frac{|V_{9\text{kHz}}|}{|V_{3\text{kHz}}|}$.

$$THD_{\text{FIL}} = \frac{|V_{9\text{kHz},\text{FIL}}|}{|V_{3\text{kHz},\text{FIL}}|} = \frac{|V_{9\text{kHz},\text{IN}}| \cdot |H(9\text{kHz})|}{|V_{3\text{kHz},\text{IN}}| \cdot |H(3\text{kHz})|}$$

Given $0.01$

So, $THD_{\text{INV}} = THD_{\text{FIL}} \cdot \frac{|H(3\text{kHz})|}{|H(9\text{kHz})|}$

For $3\text{kHz}$, $j\omega L = j(2\pi)(3000)(100\times10^{-6}) = j1.885\pi$

$$\frac{1}{j\omega C} = \frac{1}{j(2\pi)(3000)(10\times10^{-6})} = -j5.305\pi$$

For $9\text{kHz}$, $j\omega L = j5.655$, $\frac{1}{j\omega C} = -j1.768$

$$H(\omega) = \frac{1}{j\omega L + \frac{1}{j\omega C}} \cdot |H(3\text{kHz})| = \left|\frac{-5.305}{1.885 - 5.305}\right| = 1.551$$

$$|H(9\text{kHz})| = \frac{-1.768}{5.655 - 1.768} = 0.455$$

$$THD_{\text{INV}} = (0.01) \left(\frac{1.551}{0.455}\right) = 0.0341$$