ENEL 469 Assignment #1

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Assignment Objective

The purpose of this this assignment is to design and analyze a full-wave rectifier circuit which will then become the focus of the upcoming lab. The use of CAD software will be allowed for the purpose of this lab and any-and-all use of the software will be recorded appropriately. The rectifier will have the following specifications:

Transformer:
Primary winding $V_{1_{rms}} = 110V, 60Hz$
Secondary winding $V_{2_{rms}} = 18V, 60Hz$

Load Resistance:
$R_L = 1.0k\Omega$

The diodes that will be used in this assignment will all be of the 1N4005 variety.

Original Circuit Design

The following is the basic filtered full-wave bridge rectifier circuit which will be explored in this assignment:

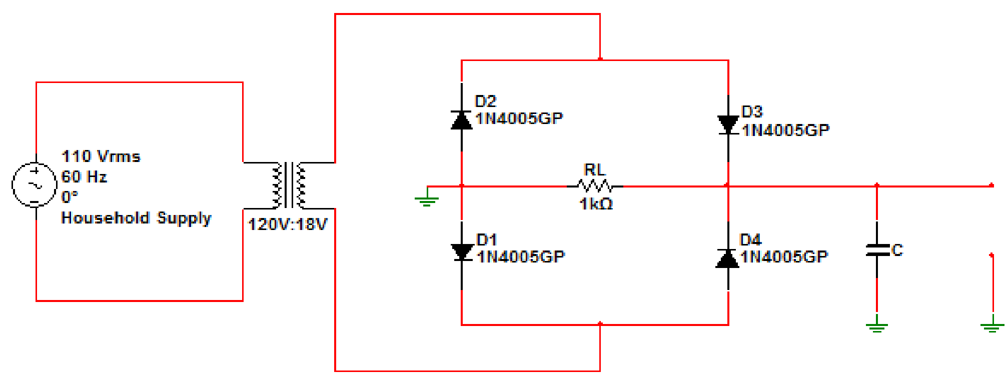

Figure 1: Full-Wave Bridge Rectifier with Filtering Capacitor

Assignment Questions/Solutions[1]

1 Calculate the peak value of the supply voltage V_s.

Given that the input voltage is a standard household supply, and assuming an ideal transformer is present in the circuit, we can make the following statements:

$$V_{s_{rms}} = \frac{V_{s_{max}}}{\sqrt{2}} = 18\text{V} \tag{1}$$

$$V_{s_{max}} = V_{s_{rms}}\sqrt{2} = 18\sqrt{2}V \approx \mathbf{25.46V} \tag{2}$$

The result for the approximate peak voltage at the supply terminals is 25.46V.

2 Determine the load current I_L. For the diodes used, identify from a relevant data-sheet the voltage drop on them and their internal resistance r_d for the 1.0kΩ load and thus calculate the peak rectified voltage V_P.

AC Supply Voltage:

$$v_s = V_{s_{max}} \sin(\omega t + \theta_0), \qquad \theta_0 = 0^\circ \tag{3}$$

Current Relationships using KCL:

$$i_D = i_L + i_C \tag{4}$$

Output Voltage using KVL:

$$v_o = v_s - 2(i_D r_d + V_0) \tag{5}$$

The load current can then be ascertained via use of Ohm's Law:

$$i_L = \frac{v_o}{R_L} = \frac{V_{s_{max}} \sin(\omega t) - 2(i_C r_d + V_0)}{R_L + 2r_d} \tag{6}$$

[1]Unless otherwise noted, all work assumes the piece-wise constant voltage-drop model of the diode.

With the aide of an appropriate data-sheet[1] for the 1N4005 diode, the following values were identified at 25°C:

Internal Voltage Drop:

$$V_0 = 0.6V \tag{7}$$

Internal Resistance:

$$r_d = \frac{\Delta I_F}{\Delta V_F} = \frac{1000 - 87.8}{1470 - 740} = 1.25\Omega \tag{8}$$

The peak rectified voltage, V_P, occurs when $i_C = 0$ and thus the whole current flows across R_L:

$$i_C = 0 \qquad \rightarrow \qquad i_D = i_L = I_{L_{max}} \tag{9}$$

$$V_P = I_{L_{max}} R_L = \frac{V_{s_{max}} - 2V_0}{R_L + 2r_d} R_L = \frac{25.46 - 1.2}{1002.5}(1000) = 24.20V \tag{10}$$

The peak rectified voltage for this circuit is 24.20V.

3 Calculate the filtering capacitor C that will result in a ripple voltage of $V_r <= 1V$, and the fraction of the 360-degree wave cycle during which the diodes are conducting. Calculate the minimal and maximal output voltage V_o.

The ripple voltage is the difference between the minimum and maximum output voltages:

$$V_r = V_P - V_{min} \leq 1 \tag{11}$$

$$V_{min} = I_{L_{min}} R_L = V_p - V_r \geq 23.20V \tag{12}$$

$$I_{L_{min}} = \frac{V_{min}}{R_L} = \frac{23.20}{1000} = 23.20mA \tag{13}$$

The capacitor will charge up with the forward current, I_C, and then once it becomes charged and the load current begins to drop, the capacitor will discharge across the load and lessen the ripple. This will continue until the load current reaches its lowest value at which point the capacitor begins to recharge again. The time that it discharges is approximately half of the supply period:

$$T_c = \frac{T_s}{2} = \frac{1}{120} sec \tag{14}$$

The charge that is discharged(lost) in this time is approximately(assuming the load current doesn't change too much):

$$\Delta Q \approx I_{L_{avg}} T_c = \frac{(I_{L_{max}} - I_{L_{min}})}{2} T_c$$

This along with the basic relationship between charge, capacitance, and change in voltage:

$$\Delta Q = C \Delta V = C V_r$$

Gives us:

$$C V_r = I_{L_{avg}} T_c \qquad \rightarrow \qquad C = \frac{I_{L_{avg}} T_c}{V_r}$$

$$C = \frac{0.0237(\frac{1}{120})}{1} \approx 198 \mu F$$

Now that we know C we can figure out the conduction range (when $i_C > 0$ the diode conducts):

$$\frac{\theta_{cond}}{2\pi} = \frac{\Delta t}{T_c}$$

4 **Calculate the Peak Inverse Voltage (PIV). Compare the calculated PIV with the maximal PIV value from the datasheet of this particular type of diodes. Verify that the calculated PIV (plus the necessary safety margin of 50%) is below the maximal PIV value for this diode.**

5 **Calculate the average diode current i_{Dav}. Why is the calculated i_{Dav} is higher than the load current I_L?**

6 **Calculate the peak diode current i_{Dmax}. Make sure it does not exceed the maximal peak diode current for 1N4005. What is the safety margin between the two currents? Why i_{Dmax} is approximately twice the value of i_{Dav}?**

7 **Now change the capacitor determined in Section 3 to two smaller standard values and to two larger standard values, and document in a table the change in the ripples. Determine and document the PIV, i_{Dav}, I_L, and i_{Dmax} (Sections 4 to 6) in each case. Which is the best filtering capacitor to be used for the 1.0kΩ load that was able to maintain the average output voltage level unchanged and below the ripple level required in Section 3?**

8 **With the optimal capacitor determined in Section 7, change the load resistor to two smaller standard values (e.g. 500Ω and 250Ω) and two standard larger values (e.g. 2kΩ and 10kΩ) and document in a table the changes in the ripples observed. Determine and document the PIV, i_{Dav}, I_L, and i_{Dmax} (Sections 4 to 6) in each case.**

9 **Present time-domain waveform plots of your final design and a Bode plot (with the optimal capacitor found in section 7 with a load resistor of 1kΩ. Explain why does the Bode plot look that way.**

Final Design

The final and optimized circuit design resulting from the calculations presented:

Conclusion

References

[1] Philips Semiconductors. *1N4001G-1N4007G Rectifiers*. Philips.