EE101 W19 Lecture 19, Mar 12, 2019

* Final Exam on March 20 8–11 am in BE 152.
- 2 pages of formulas & tables – no solved probs!
- Calculator allowed
- there will be a problem solving session organized by TAs (problems of the past 101 final, etc.)

March 13 (W) 7:10 – 10:10 pm
Oakes Acad 105

432 CHAPTER 7 AC ANALYSIS

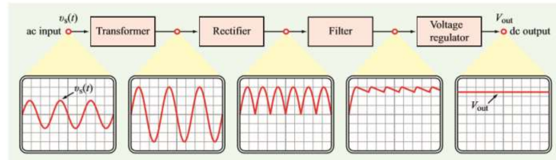


Figure 7-35: Block diagram of a basic dc power supply.

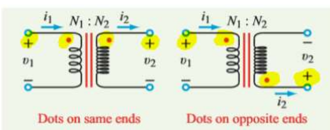


Figure 7-36: Schematic symbol for an ideal transformer. Note the reversal of the voltage polarity and current direction when the dot location at the secondary is moved from the top end of the coil to the bottom end. For both configurations:
$\frac{v_2}{v_1} = \frac{N_2}{N_1} = n, \quad \frac{i_2}{i_1} = \frac{N_1}{N_2} = \frac{1}{n}, \quad \frac{p_2}{p_1} = \frac{v_2 i_2}{v_1 i_1} = 1$

434 CHAPTER 7 AC ANALYSIS

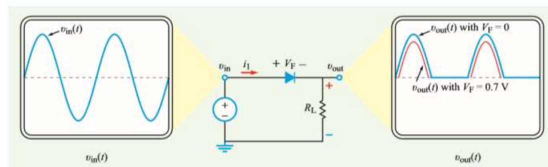
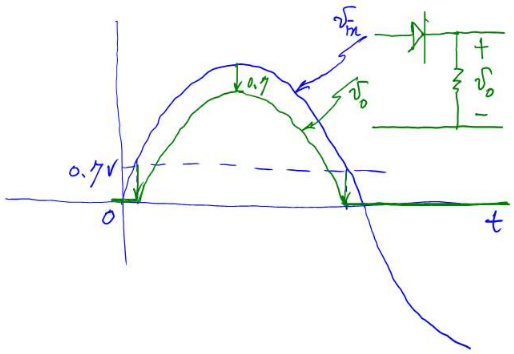


Figure 7-37: Half-wave rectifier circuit.



7-12 APPLICATION NOTE: POWER-SUPPLY CIRCUITS 435

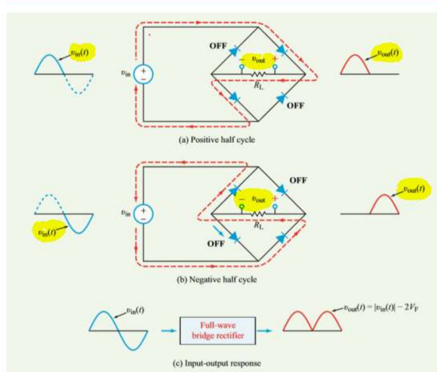


Figure 7-38: Full-wave bridge rectifier. Current flows in the same direction through the load resistor for both half cycles.

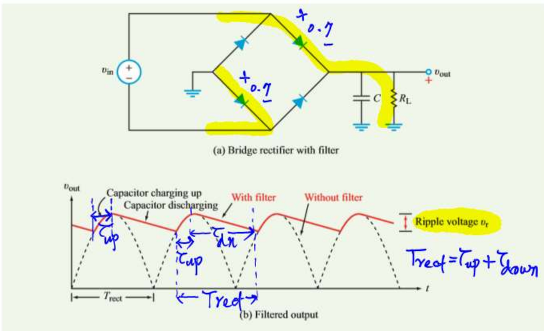
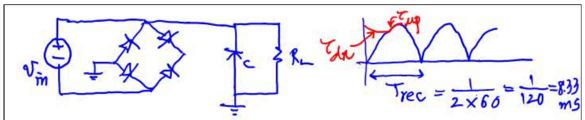


Figure 7-39: Smoothing filter reduces the variations of waveform $v_{out}(t)$.



Example 7-19: Filter Design

If the bridge rectifier circuit of Fig. 7-39(a) has a 60 Hz ac input signal, determine the values of R_L and C that would result in $\tau_{up} = T_{rect}/12$ and $\tau_{dn} = 12T_{rect}$, where T_{rect} is the period of the *rectified* waveform. Assume $R_D = 5\ \Omega$.

Solution: If the frequency of the original ac signal is 60 Hz, the frequency of the rectified waveform is 120 Hz. Hence, the period of the rectified waveform is

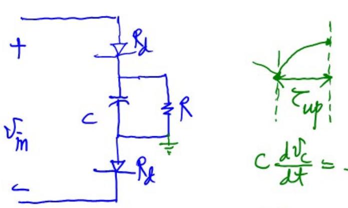
$$T_{rect} = \frac{1}{120} = 8.33 \text{ ms},$$

and the corresponding design specifications are

$$\tau_{up} = \frac{T_{rect}}{12} = 0.69 \text{ ms}, \quad \text{and} \quad \tau_{dn} = 12T_{rect} = 100 \text{ ms}.$$

Application of Eq. (7.145) leads to

$$\tau_{up} \approx 2R_D C$$



$$C\frac{dv_C}{dt} = \frac{v_{in} - v_C}{2R_d}$$

$$C\frac{dv_C}{dt} + \frac{1}{2R_d}v_C = \frac{v_{in}}{2R_d}$$

$$\frac{dv_C}{dt} + \frac{1}{2R_dC}v_C = \frac{v_{in}}{2R_dC}$$

$$sV_C(s) - v_C(t_0) + \frac{1}{2R_dC}V_C(s) = \frac{V_{in}(s)}{2R_dC}$$

$$\left(s + \frac{1}{2R_dC}\right)V_C(s) = \frac{V_{in}(s)}{2R_dC} + v_C(t_0)$$

$$V_C(s) = \left[\frac{\boxed{\frac{V_{in}(s)}{2R_dC}}}{s + \frac{1}{2R_dC}}\right] + v_C(t_0)\frac{1}{s + \frac{1}{2R_dC}}$$

$$V_{in}(s) = \mathcal{L}\left[\sin \omega t\right] = \frac{\omega}{s^2 + \omega^2}$$

$$\left[\frac{1}{2R_dC}\ \frac{\omega}{s^2+\omega^2}\ \frac{1}{s + \frac{1}{2R_dC}}\right]$$

$$= \frac{A}{s + 1/(2R_dC)} + \frac{Bs + C}{s^2 + \omega^2}$$

transient ↘ as t ↗ In steady state follows input $\sin \omega t$

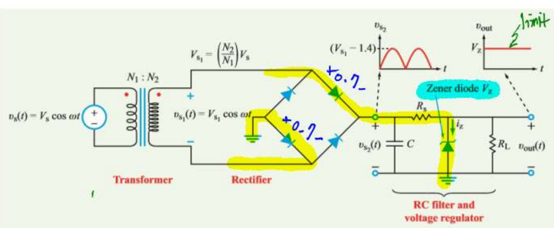


Figure 7-40: Complete power-supply circuit.

or

$$C = \frac{\tau_{up}}{2R_D} = \frac{0.69 \times 10^{-3}}{2 \times 5} = 69\ \mu\text{F}.$$

With the value of C known, application of Eq. (7.146) gives

$$R_L = \frac{\tau_{dn}}{C} = \frac{100 \times 10^{-3}}{69 \times 10^{-6}} = 1.45\ \text{k}\Omega.$$

7-12.4 Voltage Regulator

The circuit shown in Fig. 7-40 includes all of the power-supply subcircuits we have discussed thus far, plus two additional elements, namely a series resistance R_s and a ***zener diode***. When operated in reverse breakdown, the zener diode maintains the voltage across it at a constant level V_z—so long as the current i_z passing through it remains between certain limits. Since the diode is connected in parallel with R_L, the output voltage becomes equal to the ***zener voltage*** V_z, and the effective time constant of the smoothing filter becomes $\tau = R_sC$. It is worth noting that the addition of the zener diode reduces the ***peak-to-peak ripple voltage*** V_r (Fig. 7-39(b)) at the output of the RC filter by about an order of magnitude. An approximate expression for the peak-to-peak ripple voltage with the zener diode in place is given by

$$V_r = \frac{[(V_{s_1} - 1.4) - V_z]T_{rect}}{R_sC} \times \frac{(R_z \parallel R_L)}{R_s + (R_z \parallel R_L)}, \quad (7.147)$$

where V_{s_1} is the amplitude of the ac signal at the output of the transformer (Fig. 7-40), the factor 1.4 V accounts for the voltage drop across a pair of diodes in the rectifier, V_z is the manufacturer-rated zener voltage for the specific model used in the circuit, T_{rect} is the period of the rectified waveform, and R_z is the manufacturer specified value of the ***zener-diode resistance***.

Example 7-20: Power-Supply Design

A power supply with the circuit configuration shown in Fig. 7-40 has the following specifications: the input voltage is 60 Hz with an rms amplitude $V_{rms} = 110$ V where $V_{rms} = V_s/\sqrt{2}$ (the rms value of a sinusoidal function is

Time constant of the smoothing filter

$$\tau = R_sC = 50 \times 69 \times 10^{-6} = 3450 \times 10^{-6} = 3.45 \text{ ms}$$

If $R_s = 50\ \Omega$

discussed in Chapter 8), $N_1/N_2 = 5$, $C = 2$ mF, $R_s = 50\ \Omega$, $R_L = 1$ kΩ, $V_z = 24$ V, and $R_z = 20\ \Omega$. Determine υ_{out}, the ripple voltage, and the ripple fraction relative to υ_{out}.

Solution: At the secondary side of the transformer,

$$\upsilon_{s_1}(t) = \left(\frac{N_2}{N_1}\right)(V_s \cos 377t)$$
$$= \frac{1}{5} \times 110\sqrt{2}\cos 377t = 31.11 \cos 377t \text{ V}.$$

Hence, $V_{s_1} = 31.11$ V, which is greater than the zener voltage $V_z = 24$ V.

Consequently, the zener diode will limit the output voltage at

$$\upsilon_{out} = V_z = 24 \text{ V}.$$

In Example 7-19, we established that $T_{rect} = 8.33$ ms. Also,

$$R_z \parallel R_L = \frac{20 \times 1000}{20 + 1000} = 19.6\ \Omega.$$

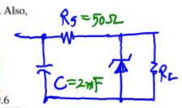
Application of Eq. (7.147) gives

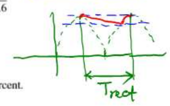
$$V_r = \frac{[(V_{s_1} - 1.4) - V_z]T_{rect}}{R_s C} \times \left[\frac{(R_z \parallel R_L)}{R_s + (R_z \parallel R_L)}\right]$$
$$= \frac{[(31.11 - 1.4) - 24]}{50 \times 2 \times 10^{-3}}(8.33 \times 10^{-3}) \times \frac{19.6}{50 + 19.6}$$
$$= 0.13 \text{ V (peak-to-peak)}.$$

Hence,

$$\text{ripple fraction} = \frac{(V_r/2)}{V_z} = \frac{0.13/2}{24} = 0.0027,$$

which represents a relative variation of less than ±0.3 percent.





7.33 Find $i_a(t)$ in the circuit of **Fig. P7.33**, given that $\upsilon_s(t) = 40\sin(200t - 20°)$ V.

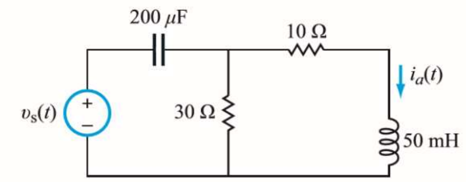


Figure P7.33: Circuit for Problem 7.33.

7.31 Find $i_s(t)$ in the circuit of **Fig. P7.31**, given that $\upsilon_s(t) = 15\cos(5 \times 10^4 t - 30°)$ V, $R = 1$ kΩ, $L = 120$ mH, and $C = 5$ nF.

ω

$j\omega L = j5\times10^4 \times 120\times10^{-3} = j6000\ \Omega$

$\frac{1}{j\omega C} = -j\frac{1}{5\times10^4(5\times10^{-9})} = -j4000$

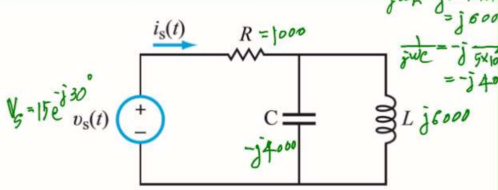


Figure P7.31: Circuit for Problem 7.31.

$$I_s = \frac{V_s}{1000 + \frac{(-j4000)(j6000)}{-j4000 + j6000}} = \frac{15e^{-j30°}}{1000 - j2400}$$

$$= \frac{15e^{-j30°}}{\sqrt{1000^2 + 2400^2}\, e^{-j\tan^{-1}\left(\frac{2400}{1000}\right)}} = \frac{15e^{-j30°}}{2600\, e^{-j67.38°}}$$

$$= 5.77 \times 10^{-3}\, e^{+j37.38°}$$

$$\Rightarrow i_s(t) = 5.77 \cos(5\times10^4 t + 37.38°)$$

*7.32 Find voltage $\upsilon_{ab}(t)$ in the circuit of **Fig. P7.32**, given that $i_s(t) = 35\sin(300t - 15°)$ mA, $R = 80\ \Omega$, $L = 15$ mH, and $C = 200\ \mu$F.

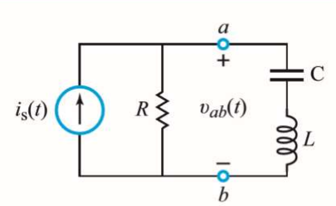


Figure P7.32: Circuit for Problem 7.32.

*7.32 Find voltage $\upsilon_{ab}(t)$ in the circuit of **Fig. P7.32**, given that $i_s(t) = 35\sin(300t - 15°)$ mA, $R = 80\ \Omega$, $L = 15$ mH, and $C = 200\ \mu$F.

$= 35\cos(300t - 15° - 90°)$

$I_s = 35e^{-j105}$

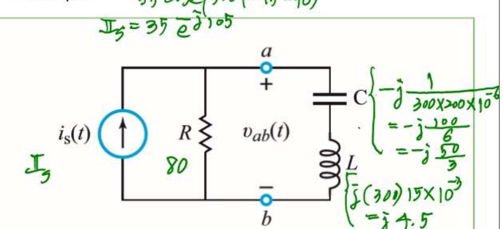


Figure P7.32: Circuit for Problem 7.32.

$$Z_{ab} = -j\frac{50}{3} + j4.5 = -j\,\frac{50-3(4.5)}{3} = -j\,\frac{36.5}{3}$$

$$Z = R \parallel Z_{ab} = \frac{80\left(-j\frac{36.5}{3}\right)}{80 - j\frac{36.5}{3}} = \frac{-j\,80\times 36.5}{240 - j36.5}$$

$$V_{ab} = I_s\, Z = 35\, e^{-j105}\, \frac{-j\,80\times 36.5}{240 - j36.5}$$

$$= \underbrace{35 \times \frac{80\times 36.5 = 2920}{\sqrt{240^2 + (36.5)^2} = 242.76}}_{= 420.99}\; e^{-j105^\circ - j90^\circ - j\left(\underbrace{-\tan^{-1}\frac{36.5}{240}}_{= -0.151\ \text{rad} = -8.65^\circ}\right)}$$

$$e^{-j\left(105^\circ - 8.65^\circ + 90^\circ\right)}$$

$$\Rightarrow v_{ab}(t) = 420.99 \cos(300t - 186.35^\circ) = \cos(300t - 96.35^\circ - 90^\circ) = \sin(300t - 96.35^\circ)$$