

SOLUTIONS MANUAL

POWER ELECTRONICS

CIRCUITS, DEVICES,
AND APPLICATIONS

THIRD EDITION

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CHAPTER 2

POWER SEMICONDUCTOR DIODES AND CIRCUITS

Problem 2-1

$$t_{rr} = 5 \mu\text{s} \text{ and } di/dt = 80 \text{ A}/\mu\text{s}$$

(a) From Eq. (2-10),

$$Q_{RR} = 0.5 (di/dt) t_{rr}^2 = 0.5 \times 80 \times 5^2 \times 10^{-6} = 1000 \mu\text{C}$$

(b) From Eq. (2-11),

$$I_{RR} = \sqrt{2Q_{RR} \frac{di}{dt}} = \sqrt{2 \times 1000 \times 80} = 400 \text{ A}$$

Problem 2-2

$V_T = 25.8 \text{ mV}$, $V_{D1} = 1.0 \text{ V}$ at $I_{D1} = 50 \text{ A}$, and $V_{D2} = 1.5 \text{ V}$ at $I_{D2} = 600 \text{ A}$

Taking natural (base e) logarithm on both sides of Eq. (2-3),

$$\ln I_D = \ln I_S + \frac{v_D}{\eta V_T}$$

which, after simplification, gives the diode voltage V_D as

$$v_D = \eta V_T \ln \left(\frac{I_D}{I_S} \right)$$

If I_{D1} is the diode current corresponding to diode voltage V_{D1} , we get

$$V_{D1} = \eta V_T \ln \left(\frac{I_{D1}}{I_S} \right)$$

Similarly, if V_{D2} is the diode voltage corresponding to the diode current I_{D2} , we get

$$V_{D2} = \eta V_T \ln \left(\frac{I_{D2}}{I_S} \right)$$

Therefore, the difference in diode voltages can be expressed by

$$V_{D2} - V_{D1} = \eta V_T \ln\left(\frac{I_{D2}}{I_S}\right) - \eta V_T \ln\left(\frac{I_{D1}}{I_S}\right) = \eta V_T \ln\left(\frac{I_{D2}}{I_{D1}}\right)$$

(a) For $V_{D2} = 1.5$ V, $V_{D1} = 1.0$ V, $I_{D2} = 600$ A, and $I_{D1} = 50$ A,

$$1.5 - 1.0 = \eta \times 0.0258 \times \ln\left(\frac{600}{50}\right), \text{ which give } \eta = 7.799$$

(b) For $V_{D1} = 1.0$ V, $I_{D1} = 50$ A, and $\eta = 7.999$

$$1.0 = 7.799 \times 0.0258 \ln\left(\frac{50}{I_S}\right), \text{ which gives } I_S = 0.347 \text{ A.}$$

Problem 2-3

$$V_{D1} = V_{D2} = 2000 \text{ V}, R_1 = 100 \text{ k}\Omega$$

(a) From Fig. P2-3, the leakage current are: $I_{S1} = 17$ mA and $I_{S2} = 25$ mA

$$I_{R1} = V_{D1}/R_1 = 2000/100000 = 20 \text{ mA}$$

(b) From Eq. (2-12), $I_{S1} + I_{R1} = I_{S2} + I_{R2}$

$$\text{or } 17 + 20 = 25 + I_{R2}, \text{ or } I_{R2} = 12 \text{ mA}$$

$$R_2 = 2000/12 \text{ mA} = 166.67 \text{ k}\Omega$$

Problem 2-4

For $V_D = 1.5$ V, Fig. P2-3 gives $I_{D1} = 140$ A and $I_{D2} = 50$ A

Problem 2-5

$$I_T = 200 \text{ A}, v = 2.5$$

$$I_1 = I_2, I_1 = I_T/2 = 200/2 = 100 \text{ A}$$

For $I_1 = 100$ A, Fig. P2-3 yields $V_{D1} = 1.1$ V and $V_{D2} = 1.95$ V

$$v = V_{D1} + I_1 R_1 \text{ Or } 2.5 = 1.1 + 100 R_1 \text{ or } R_1 = 14 \text{ m}\Omega$$

$$v = V_{D2} + I_2 R_2 \text{ Or } 2.5 = 1.95 + 100 R_2 \text{ or } R_2 = 5.5 \text{ m}\Omega$$

Problem 2-6

$$R_1 = R_2 = 10 \text{ k}\Omega, V_s = 5 \text{ kV}, I_{S1} = 25 \text{ mA}, I_{S2} = 40 \text{ mA}$$

$$\text{From Eq. (2-12), } I_{S1} + I_{R1} = I_{S2} + I_{R2}$$

$$\text{or } I_{S1} + V_{D1}/R_1 = I_{S2} + V_{D2}/R_2$$

$$25 \times 10^{-3} + V_{D1}/10000 = 40 \times 10^{-3} + V_{D2}/10000$$

$$V_{D1} + V_{D2} = V_s = 5000$$

$$\text{Solving for } V_{D1} \text{ and } V_{D2} \text{ gives } V_{D1} = 2575 \text{ V and } V_{D2} = 2425 \text{ V}$$

Problem 2-7

$t_1 = 100 \mu\text{s}, t_2 = 300 \mu\text{s}, t_3 = 500 \mu\text{s}, f = 250 \text{ Hz}, f_s = 250 \text{ Hz}, I_m = 500 \text{ A}$
and $I_a = 200 \text{ A}$

(a) The average current is $I_{av} = 2I_m ft_1/\pi - I_a (t_3 - t_2)f = 7.96 - 10 = -2.04$
A.

(b) For sine wave, $I_{r1} = I_m \sqrt{ft_1/2} = 55.9 \text{ A}$ and for a rectangular negative
wave, $I_{r2} = I_a \sqrt{f(t_3 - t_2)} = 44.72 \text{ A}$

The rms current is $I_{rms} = \sqrt{55.92^2 + 44.722^2} = 71.59 \text{ A}$

(c) The peak current varies from 500 A to -200 A.

Problem 2-8

$t_1 = 100 \mu\text{s}, t_2 = 200 \mu\text{s}, t_3 = 400 \mu\text{s}, t_4 = 800 \mu\text{s}, f = 250 \text{ Hz}, I_a = 150 \text{ A}, I_b$
 $= 100 \text{ A}$ and $I_p = 300 \text{ A}$

(a) The average current is

$$I_{av} = I_a ft_3 + I_b f(t_5 - t_4) + 2(I_p - I_a) f(t_2 - t_1)/\pi = 15 + 5 + 2.387 = 22.387 \text{ A.}$$

(b) $I_{r1} = (I_p - I_a) \sqrt{f(t_2 - t_1)/2} = 16.77 \text{ A,}$

$$I_{r2} = I_a \sqrt{ft_3} = 47.43 \text{ A and } I_{r3} = I_b \sqrt{f(t_5 - t_4)} = 22.36 \text{ A}$$

The rms current is $I_{rms} = \sqrt{(16.772^2 + 47.432^2 + 22.362^2)} = 55.05 \text{ A}$

Problem 2-9

$R = 22 \Omega$, $C = 10 \mu\text{F}$, $V_o = 220 \text{ V}$

$$0 = v_R + v_C = v_R + \frac{1}{C} \int i dt + v_C(t=0)$$

With initial condition: $v_C(t=0) = -V_o$, the current is

$$i(t) = \frac{V_o}{R} e^{-t/RC}$$

The capacitor voltage is

$$v_C(t) = -Ri = -V_o e^{-t/RC} = -220 e^{-t \times 10^6 / 220}$$

(b) The energy dissipated is

$$W = 0.5 C V_o^2 = 0.5 \times 10 \times 10^{-6} \times 220 \times 220 = 0.242 \text{ J.}$$

Problem 2-10

$R = 10 \Omega$, $L = 5 \text{ mH}$, $V_s = 220 \text{ V}$, $I_1 = 10 \text{ A}$

The switch current is described by

$$V_S = L \frac{di}{dt} + Ri$$

With initial condition: $i(t=0) = I_1$,

$$i(t) = \frac{V_S}{R} (1 - e^{-tR/L}) + I_1 e^{-tR/L} = 22 - 12 e^{-2000t} \text{ A}$$

Problem 2-11

$$V_S = L \frac{di}{dt} + \frac{1}{C} \int i dt + v_C(t=0)$$

With initial condition: $i(t=0) = I_o$ and $v_C(t=0) = 0$, we get

$$i(t) = I_o \cos(\omega_o t) + V_S \sqrt{\frac{C}{L}} \sin(\omega_o t)$$

The capacitor voltage is

$$v_c(t) = \frac{1}{C} \int i dt = I_o \sqrt{\frac{L}{C}} \sin(\omega_o t) - V_S \cos(\omega_o t) + V_S$$

where $\omega_o = 1/\sqrt{CL}$

Problem 2-12

Fig. p2-12a:

(a) $L di/dt$ or $i(t) = V_s t/L$

(b) $di/dt = V_s/L$;

(d) di/dt (at $t= 0$) = V_s/L .

Fig. p2-12b:

(a) $\frac{1}{C} \int i dt + Ri = V_S - V_o$ or $i(t) = \frac{V_s - V_o}{R} e^{-t/RC}$

(b) $\frac{di}{dt} = \frac{V_s - V_o}{R^2 C} e^{-t/RC}$

(d) At $t = 0$, $di/dt = (V_s - V_o)/(R^2 C)$

Fig. p2-12c:

(a) $L \frac{di}{dt} + Ri = V_s$ or $i(t) = \frac{V_s}{R} e^{-tR/L}$

(b) $\frac{di}{dt} = -\frac{V_s}{L} e^{-tR/L}$

(d) At $t = 0$, $di/dt = V_s/L$

Fig. p2-12d:

$$(a) \quad V_S = L \frac{di}{dt} + \frac{1}{C} \int i dt + v_C(t=0)$$

With initial condition: $i(t=0) = 0$ and $v_C(t=0) = V_o$,

$$i(t) = (V_S - V_o) \sqrt{\frac{C}{L}} \sin(\omega_o t) = I_p \sin(\omega_o t)$$

$$\text{where } \omega_o = 1/\sqrt{LC}$$

$$(b) \quad \frac{di}{dt} = \frac{V_S - V_o}{L} \cos(\omega_o t)$$

$$(d) \quad \text{At } t = 0, di/dt = (V_s - V_o)/L$$

Fig. p2-12e:

At $t=0$, the inductor behaves as an open circuit and a capacitor behaves as a short circuit. Inductor L_1 limits the initial di/dt only. Thus, the initial di/dt is $di/dt = V_s/L_1 = V_s/20\mu\text{H} = V_s/20 \text{ A}/\mu\text{s}$

Problem 2-13

$V_s = 220 \text{ V}$, $L = 5 \text{ mH}$, $C = 10 \mu\text{F}$, $R = 22 \Omega$ and $V_o = 50 \text{ V}$

$$(a) \text{ From Eq. (2-40), } \alpha = 22 \times 10^3 / (2 \times 5) = 2200$$

$$\text{From Eq. (2-41), } \omega_o = 1/\sqrt{LC} = 4472 \text{ rad/s}$$

$$\omega_r = \sqrt{4472^2 - 2200^2} = 3893 \text{ rad/s}$$

Since $\alpha < \omega_o$, it is an under-damped case and the solution is of the form

$$i(t) = e^{-\alpha t} [A_1 \cos(\omega_r t) + A_2 \sin(\omega_r t)]$$

At $t = 0$, $i(t=0) = 0$ and this gives $A_1 = 0$.

$$i(t) = e^{-\alpha t} A_2 \sin(\omega_r t)$$

$$\frac{di}{dt} = \omega_r \cos(\omega_r t) A_2 e^{-\alpha t} - \alpha \sin(\omega_r t) A_2 e^{-\alpha t}$$

$$\left. \frac{di}{dt} \right|_{t=0} = \omega_r A_2 = \frac{V_s}{L}$$

or $A_2 = V_s / (\omega_r L) = 220 \times 1000 / (3893 \times 5) = 11.3$

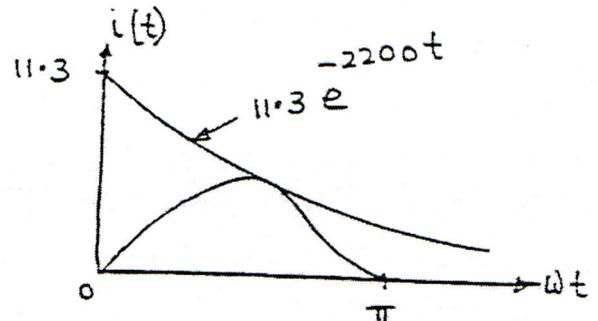
The final expression for current $i(t)$ is

$$i(t) = 11.3 \times \sin(3893t) e^{-2200t} \text{ A}$$

(b) The conduction time is

$$\omega_r t_1 = \pi \text{ or } t_1 = \pi / 3893 = 807 \mu\text{s}$$

(c) The sketch for $i(t)$ is shown.



Problem 2-14

$V_s = 200 \text{ V}$, $L_m = 150 \mu\text{H}$, $N_1 = 10$, $N_2 = 200$ and $t_1 = 100 \mu\text{s}$

The turns ratio is $a = N_2 / N_1 = 200 / 10 = 20$

(a) From Eq. (2-52) the reverse voltage of diode,

$$v_D = 200 \times (1 + 20) = 4620 \text{ V}$$

(b) From Eq. (2-55) the peak value of primary current,

$$I_o = 220 \times 100 / 150 = 146.7 \text{ A}$$

(c) The peak value of secondary current $I_o' = I_o / a = 146.7 / 20 = 7.3 \text{ A}$

(d) From Eq. (2-58) the conduction time of diode,

$$t_2 = 20 \times 100 = 2000 \mu\text{s}.$$

(e) The energy supplied by the source

$$W = \int_0^{t_1} v i dt = \int_0^{t_1} V_S \frac{V_S}{L_m} t dt = \frac{1}{2} \frac{V_S^2}{L_m} t_1^2$$

From Eq. (2-55), $W = 0.5 L_m I_0^2 = 0.5 \times 150 \times 10^{-6} \times 146.72 = 1.614 \text{ J}$

Problem 2-15

(a) $i_c = i_d + I_m$

$$v_c = \frac{1}{C} \int i_c dt + v_c(t=0) = -L \frac{di_d}{dt} = -L \frac{di_c}{dt}$$

With initial condition: $i_c(t=0) = I_m$ and $v_c(t=0) = -V_S$,

$$i(t) = V_S \sqrt{\frac{C}{L}} \sin(\omega_o t) + I_m \cos(\omega_o t)$$

where $\omega_o = 1/\sqrt{LC}$

$$v_c(t) = \frac{1}{C} \int i_c(t) dt = I_m \sqrt{\frac{L}{C}} \sin(\omega_o t) - V_S \cos(\omega_o t)$$

$$i_d(t) = V_S \sqrt{\frac{C}{L}} \sin(\omega_o t) + I_m \cos(\omega_o t) - I_m$$

(b) For $i_d(t = t_1) = 0$

$$i_d(t = t_1) = V_S \sqrt{\frac{C}{L}} \sin(\omega_o t_1) + I_m \cos(\omega_o t_1) - I_m = 0$$

or $\cos(\alpha) \sin(\omega_o t_1) + \sin(\alpha) \cos(\omega_o t_1) = \frac{1}{\sqrt{1+x^2}}$

or $\sin(\omega_o t_1 + \alpha) = \frac{1}{\sqrt{1+x^2}}$

which gives the time t_1

$$\omega_o t_1 = \sin^{-1} \left[\frac{1}{\sqrt{1+x^2}} \right] - \alpha = \sin^{-1} \left[\frac{1}{\sqrt{1+x^2}} \right] - \tan^{-1} \left(\frac{1}{x} \right)$$

where $x = \frac{V_S}{I_m} \sqrt{\frac{C}{L}}$

(c) For $v_c(t=t_q) = 0$

$$v_C(t) = I_m \sqrt{\frac{L}{C}} \sin(\omega_o t) - V_s \cos(\omega_o t) = 0$$

or $t_q = \sqrt{LC} \tan^{-1}(x)$

(d) The time for the capacitor to recharge to the supply voltage at a constant current of I_m , is

$$v_C(t=t_1) = V_s = \frac{1}{C} \int_0^{t_1} I_m dt$$

$$t_1 = V_s C / I_m$$

The total time for discharge and recharge is $t_2 = t_1 + t_q$

CHAPTER 3
DIODE RECTIFIERS

Problem 3-1

$$V_m = 170 \text{ V}, R = 10 \ \Omega, f = 60 \text{ Hz}$$

$$\text{From Eq. (3-21), } V_d = 0.6366 V_m = 0.6366 \times 170 = 113.32 \text{ V}$$

Problem 3-2

$$V_m = 170 \text{ V}, R = 10 \ \Omega, f = 60 \text{ Hz and } L_c = 0.5 \text{ mH}$$

$$\text{From Eq. (3-21), } V_{dc} = 0.6366 V_m = 0.6366 \times 170 = 113.32 \text{ V}$$

$$I_{dc} = V_{dc}/R = 113.32/10 = 11.332 \text{ A}$$

Since there are two commutations per cycle, Eq. (3-79) gives the output voltage reduction, $V_x = 2 \times 60 \times 0.5 \times 10^{-3} \times 11.332 = 0.679 \text{ V}$ and the effective output voltage is $(113.32 - 0.679) = 112.64 \text{ V}$

Problem 3-3

$$R = 10 \ \Omega, V_m = 170 \text{ V}, f = 60 \text{ Hz}$$

$$\text{For a six-phase star rectifier } q = 6 \text{ in Eqs. (3-32) and from Eq. (3-32), } V_{dc} = 170 (6/\pi) \sin (\pi/6) = 162.34 \text{ V}$$

Problem 3-4

$$R = 10 \ \Omega, V_m = 170 \text{ V}, f = 60 \text{ Hz}, L_c = 0.5 \text{ mH}$$

$$\text{For a six-phase star-rectifier, } q = 6 \text{ in Eq. (3-69). From Eq. (3-32), } V_{dc} = 170 (6/\pi) \sin (\pi/6) = 162.34, I_{dc} = 162.34/10 = 16.234 \text{ A.}$$

Since there are six commutations per cycle, Eq. (3-79) gives the output voltage reduction, $V_x = 6 \times 60 \times 0.5 \times 10^{-3} \times 16.234 = 2.92 \text{ V}$ and the effective output voltage is $(162.34 - 2.92) = 159.42 \text{ V}$

Problem 3-5

$$R = 100 \Omega, V_s = 280 \text{ V}, f = 60 \text{ Hz}$$

$$V_m = 280 \times \sqrt{2}/\sqrt{3} = 228.6 \text{ V}$$

$$\text{From Eq. (3-40), } V_{dc} = 1.6542 \times 228.6 = 378.15 \text{ V}$$

Problem 3-6

$$R = 100 \Omega, V_s = 280 \text{ V}, f = 60 \text{ Hz and } L_c = 0.5 \text{ mH}$$

$$V_m = 280 \times \sqrt{2}/\sqrt{3} = 228.6 \text{ V}$$

$$\text{From Eq. (3-40), } V_{dc} = 1.6542 \times 228.6 = 378.15 \text{ V}$$

$$I_{dc} = V_{dc}/R = 378.15/100 = 3.7815 \text{ A}$$

Since there are six commutations per cycle, Eq. (3-79) gives the output voltage reduction, $V_x = 6 \times 60 \times 0.5 \times 10^{-3} \times 3.7815 = 6.81 \text{ V}$ and the effective output voltage is $(378.15 - 6.81) = 371.34 \text{ V}$

Problem 3-7

$$V_{dc} = 400 \text{ V}, R = 10 \Omega$$

$$\text{From Eq. (3-21), } V_{dc} = 400 = 0.6366 V_m \text{ or } V_m = 628.34 \text{ V}$$

$$\text{The rms phase voltage is } V_s = V_m/\sqrt{2} = 628.34/\sqrt{2} = 444.3 \text{ V}$$

$$I_{dc} = V_{dc}/R = 400/10 = 40 \text{ A}$$

Diodes:

$$\text{Peak current, } I_p = 628.34/10 = 62.834 \text{ A}$$

$$\text{Average current, } I_d = I_{dc}/2 = 40/2 = 20 \text{ A}$$

$$\text{RMS current, } I_R = 62.834/\sqrt{2} = 44.43 \text{ A}$$

Transformer:

$$\text{RMS voltage, } V_s = V_m/\sqrt{2} = 444.3 \text{ V}$$

$$\text{RMS current, } I_s = I_m/\sqrt{2} = 44.43 \text{ A}$$

$$\text{Volt-amp, } VI = 444.3 \times 44.43 = 19.74 \text{ kVA}$$

$$P_{dc} = (0.6366 V_m)^2/R \text{ and } P_{ac} = V_s I_s = V_m^2 / 2R$$

TUF = $P_{dc}/P_{ac} = 0.6366^2 \times 2 = 0.8105$ and the de-rating factor of the transformer is $1/TUF = 1.2338$.

Problem 3-8

$$V_{dc} = 750 \text{ V}, I_{dc} = 9000 \text{ A}$$

$$\text{From Eq. (3-40), } V_{dc} = 750 = 1.6542 V_m \text{ or } V_m = 453.39 \text{ V}$$

$$\text{The phase voltage is } V_s = V_m/\sqrt{2} = 453.39/\sqrt{2} = 320.59 \text{ V}$$

Diodes:

$$\text{Peak current, } I_p = 9000 \text{ A}$$

$$\text{Average current, } I_d = I_{dc}/2 = 9000/2 = 4500 \text{ A}$$

$$\text{RMS current, } I_R = 9000/\sqrt{2} = 6363.96 \text{ A}$$

Transformer:

$$\text{RMS voltage, } V_s = 320.59 \text{ V}$$

$$\text{RMS current, } I_s = I_p = 9000 \text{ A}$$

$$\text{Volt-amp per phase, } VI = 320.59 \times 9000 = 2885.31 \text{ kVA}$$

TUF = $P_{dc}/P_{ac} = 750 \times 9000/(3 \times 2885.31) = 0.7798$ and the de-rating factor of the transformer is $1/TUF = 1.2824$

Problem 3-9

$$V_m = 170 \text{ V}, f = 60 \text{ Hz}, R = 15 \Omega \text{ and } \omega = 2\pi f = 377 \text{ rad/s}$$

From Eq. (3-22), the output voltage is

$$v_L(t) = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi} \cos(2\omega t) - \frac{4V_m}{15\pi} \cos(4\omega t) - \frac{4V_m}{35\pi} \cos(6\omega t) - \dots$$

$$\text{The load impedance, } Z = R + j(n\omega L) = \sqrt{R^2 + (n\omega L)^2} \angle \theta_n$$

$$\text{and } \theta_n = \tan^{-1}(n\omega L / R)$$

and the load current is given by

$$i_L(t) = I_{dc} - \frac{4V_m}{\pi\sqrt{R^2 + (n\omega L)^2}} \left[\frac{1}{3} \cos(2\omega t - \theta_2) - \frac{1}{15} \cos(4\omega t - \theta_4) - \frac{1}{35} \cos(6\omega t - \theta_6) - \dots \right]$$

where $I_{dc} = \frac{V_{dc}}{R} = \frac{2V_m}{\pi R}$

The rms value of the ripple current is

$$I_{ac}^2 = \frac{(4V_m)^2}{2\pi^2[R^2 + (2\omega L)^2]} \left(\frac{1}{3}\right)^2 + \frac{(4V_m)^2}{2\pi^2[R^2 + (4\omega L)^2]} \left(\frac{1}{15}\right)^2 + \frac{(4V_m)^2}{2\pi^2[R^2 + (6\omega L)^2]} \left(\frac{1}{35}\right)^2 + \dots$$

Considering only the lowest order harmonic ($n = 2$) and neglecting others,

$$I_{ac} = \frac{4V_m}{\sqrt{2\pi}\sqrt{R^2 + (2\omega L)^2}} \left(\frac{1}{3}\right)$$

Using the value of I_{dc} and after simplification, the ripple factor is

$$RF = \frac{I_{ac}}{I_{dc}} = \frac{0.481}{\sqrt{1 + (2\omega L/R)^2}} = 0.04$$

$$0.481^2 = 0.04^2 [1 + (2 \times 377 L/15)^2] \text{ or } L = 238.4 \text{ mH}$$

Problem 3-10

$V_m = 170 \text{ V}$, $f = 60 \text{ Hz}$, $R = 15 \Omega$ and $\omega = 2\pi f = 377 \text{ rad/s}$

For $q = 6$, Eq. (3-39) gives the output voltage as

$$v_L(t) = 0.9549V_m \left[1 + \frac{2}{35} \cos(6\omega t) - \frac{2}{143} \cos(12\omega t) + \dots \right]$$

The load impedance, $Z = R + j(n\omega L) = \sqrt{R^2 + (n\omega L)^2} \angle \theta_n$

and $\theta_n = \tan^{-1}(n\omega L/R)$

and the load current is

$$i_L(t) = I_{dc} - \frac{0.9549V_m}{\sqrt{R^2 + (n\omega L)^2}} \left[\frac{2}{35} \cos(6\omega t - \theta_6) - \frac{2}{143} \cos(12\omega t - \theta_{12}) + \dots \right]$$

where
$$I_{dc} = \frac{V_{dc}}{R} = \frac{0.9549V_m}{R}$$

The rms value of the ripple current is

$$I_{ac}^2 = \frac{(0.9549V_m)^2}{2[R^2 + (6\omega L)^2]} \left(\frac{2}{35}\right)^2 + \frac{(0.9549V_m)^2}{2[R^2 + (12\omega L)^2]} \left(\frac{2}{143}\right)^2 + \dots$$

Considering only the lowest order harmonic (n = 6) and neglecting others,

$$I_{ac} = \frac{0.9549V_m}{\sqrt{2}\sqrt{R^2 + (6\omega L)^2}} \left(\frac{2}{35}\right)$$

Using the value of I_{dc} and after simplification, the ripple factor is

$$RF = \frac{I_{ac}}{I_{dc}} = \frac{1}{\sqrt{2} \times \sqrt{1 + (6\omega L/R)^2}} \left(\frac{2}{35}\right) = 0.02$$

$$0.0404^2 = 0.02^2 [1 + (6 \times 377 L/15)^2] \text{ or } L = 11.64 \text{ mH}$$

Problem 3-11

$$E = 20 \text{ V}, I_{dc} = 10 \text{ A}, V_p = 120 \text{ V}, V_s = V_p/n = 120/2 = 60 \text{ V}$$

$$V_m = \sqrt{2} V_s = \sqrt{2} \times 60 = 84.85 \text{ V}$$

(i) From Eq. (3-17), $\alpha = \sin^{-1} (20/84.85) = 15.15^\circ$ or 0.264 rad

$$\beta = 180 - 15.15 = 164.85^\circ$$

The conduction angle is $\delta = \beta - \alpha = 164.85 - 15.15 = 149.7^\circ$

(ii) Equation (3-18) gives the resistance R as

$$R = \frac{1}{2\pi I_{dc}} \left[2V_m \cos \alpha + 2\alpha E - \pi E \right]$$

$$R = \frac{1}{2\pi \times 10} \left[2 \times 84.85 \times \cos 15.15^\circ + 2 \times 20 \times 0.264 - \pi \times 20 \right] = 1.793 \Omega$$

(iii) Equation (3-19) gives the rms battery current I_{rms} as

$$I_{rms}^2 = \frac{1}{2\pi R^2} \left[\left(\frac{V_m^2}{2} + E^2 \right) \times (\pi - 2\alpha) + \frac{V_m^2}{2} \sin 2\alpha - 4V_m E \cos \alpha \right] = 272.6$$

or $I_{rms} = \sqrt{272.6} = 16.51 \text{ A}$

The power rating of R is $P_R = 16.51^2 \times 1.793 = 488.8 \text{ W}$

(iv) The power delivered P_{dc} to the battery is

$$P_{dc} = E I_{dc} = 20 \times 10 = 200 \text{ W}$$

$$h P_{dc} = 100 \quad \text{or} \quad h = 200/P_{dc} = 200/200 = 1 \text{ hr}$$

(v) The rectifier efficiency η is

$$\eta = \frac{P_{dc}}{P_{dc} + P_R} = \frac{200}{200 + 488.8} = 29\%$$

(vi) The peak inverse voltage PIV of the diode is

$$\text{PIV} = V_m + E = 84.85 + 20 = 104.85 \text{ V}$$

Problem 3-12

It is not known whether the load current is continuous or discontinuous. Let us assume that the load current is continuous and proceed with the solution. If the assumption is not correct, the load current will be zero current and then move to the case for a discontinuous current.

$$\text{(a) } R = 5 \Omega, L = 4.5 \text{ mH}, f = 60 \text{ Hz}, \omega = 2\pi \times 60 = 377 \text{ rad/s}, V_s = 120 \text{ V}, \\ Z = [R^2 + (\omega L)^2]^{1/2} = 5.28 \Omega, \text{ and } \theta = \tan^{-1}(\omega L/R) = 18.74^\circ$$

(i) The steady-state load current at $\omega t = 0$, $I_1 = 6.33 \text{ A}$. Since $I_1 > 0$, the load current is continuous and the assumption is correct.

(ii) The numerical integration of i_L in Eq. (3-27) yields the average diode current as $I_d = 8.8 \text{ A}$

(iii) By numerical integration of i_L^2 between the limits $\omega t = 0$ to π , we get the rms diode current as $I_r = 13.83 \text{ A}$.

(iv) The rms output current $I_{rms} = \sqrt{2} I_r = \sqrt{2} \times 13.83 = 19.56 \text{ A}$

Problem 3-13

(a) $R = 5 \Omega$, $L = 2.5 \text{ mH}$, $f = 60 \text{ Hz}$, $\omega = 2 \pi \times 60 = 377 \text{ rad/s}$, $V_{ab} = 208 \text{ V}$,
 $Z = [R^2 + (\omega L)^2]^{1/2} = 5.09 \Omega$, and $\theta = \tan^{-1} (\omega L/R) = 10.67^\circ$

(i) The steady-state load current at $\omega t = \pi/3$, $I_1 = 50.6 \text{ A}$.

(ii) The numerical integration of i_L in Eq. (3-47) yields the average diode current as $I_d = 17.46 \text{ A}$. Since $I_1 > 0$, the load current is continuous.

(iii) By numerical integration of i_L^2 between the limits $\omega t = \pi/3$ to $2\pi/3$, we get the rms diode current as $I_r = 30.2 \text{ A}$.

(iv) The rms output current $I_{rms} = \sqrt{3} I_r = \sqrt{3} \times 30.2 = 52.31 \text{ A}$

Problem 3-14

RF = 5%, $R = 200 \Omega$ and $f = 60 \text{ Hz}$

(a) Solving for C_e in Eq. (3-62),

$$C_e = \frac{1}{4 \times 60 \times 200} \left[1 + \frac{1}{\sqrt{2} \times 0.05} \right] = 315.46 \mu\text{F}$$

(b) From Eq. (3-61), the average load voltage V_{dc} is

$$V_{dc} = 169.7 - \frac{169.7}{4 \times 60 \times 200 \times 415.46 \times 10^{-6}} = 169.7 - 11.21 = 158.49 \text{ V}$$

Problem 3-15

RF = 5%, $R = 200 \Omega$, and $f = 60 \text{ Hz}$

(a) For a half-wave rectifier, the frequency of output ripple voltage is the same as the supply frequency. Thus, the constant 4 in Eq. (3-62) should be changed to 2.

Solving for C_e in Eq. (3-62),

$$C_e = \frac{1}{2 \times 60 \times 200} \left[1 + \frac{1}{\sqrt{2} \times 0.05} \right] = 630.92 \mu\text{F}$$

(b) From Eq. (3-61), the average load voltage V_{dc} is

$$V_{dc} = 169.7 - \frac{169.7}{2 \times 60 \times 200 \times 415.46 \times 10^{-6}} = 169.7 - 22.42 = 147.28 \text{ V}$$

Problem 3-16

$$\omega = 2 \pi \times 60 = 377 \text{ rad/s}, V_{dc} = 48 \text{ V}, V_s = 120 \text{ V}, V_m = \sqrt{2} \times 120 = 169.7 \text{ V}$$

(a) Voltage ratio $x = V_{dc}/V_m = 48/169.7 = 28.28 \%$

$$\alpha = \sin^{-1}(x) = 16.43^\circ$$

Solving Eq. (3-70) for β gives: $\beta = 117.43^\circ$

Equation (3-105) gives the current ratio $I_{dc}/I_{pk} = 13.425 \%$

Thus, $I_{pk} = I_{dc}/0.13425 = 186.22 \text{ A}$

The required value of inductance is

$$L_e = V_m/(\omega I_{pk}) = 169.7/(377 \times 186.22) = 2.42 \text{ mH.}$$

Equation (3-106) gives the current ratio $I_{rms}/I_{pk} = 22.59 \%$

Thus $I_{rms} = 0.2259 \times I_{pk} = 0.2259 \times 186.22 = 42.07 \text{ A}$

(b) $I_{dc} = 15 \text{ A}$, $L_e = 6.5 \text{ mH}$, $I_{pk} = V_m/(\omega L_e) = 169.7/(377 \times 6.5 \text{ mH}) = 69.25 \text{ A}$

$$y = I_{dc}/I_{pk} = 15/69.25 = 21.66\%$$

Using linear interpolation, we get

$$\begin{aligned} x &= x_n - (x_{n+1} - x_n) (y_n - y)/(y_{n+1} - y_n) \\ &= 10 - (15 - 10) (25.5 - 21.66)/(21.5 - 25.5) = 14.8\% \end{aligned}$$

$$V_{dc} = x V_m = 0.148 \times 169.7 = 25.12 \text{ V}$$

$$\begin{aligned} \alpha &= \alpha_n - (\alpha_{n+1} - \alpha_n) (y_n - y)/(y_{n+1} - y_n) \\ &= 5.74 - (8.63 - 5.74) (25.5 - 21.66)/(21.5 - 25.5) = 8.51^\circ. \end{aligned}$$

$$\begin{aligned} \beta &= \beta_n - (\beta_{n+1} - \beta_n) (y_n - y)/(y_{n+1} - y_n) \\ &= 139.74 - (131.88 - 139.74) (25.5 - 21.66)/(21.5 - 25.5) = 132.19^\circ. \end{aligned}$$

$$\begin{aligned} z &= I_{rms}/I_{pk} = z_n - (z_{n+1} - z_n) (y_n - y)/(y_{n+1} - y_n) \\ &= 37.06 - (32.58 - 37.06) (25.5 - 21.66)/(21.5 - 25.5) = 32.76\% \end{aligned}$$

Thus $I_{rms} = 0.3276 \times I_{pk} = 0.3276 \times 69.25 = 22.69 \text{ A}$

(a)

$$f := 60 \quad V_{dc} := 48 \quad I_{dc} := 25 \quad \omega := 2 \cdot \pi \cdot f \quad \omega = 376.99$$

$$V_s := 120 \quad V_m := \sqrt{2} \cdot V_s$$

$$x := \frac{V_{dc}}{V_m} \quad \alpha := \arcsin(x) \quad 180 \cdot \frac{\alpha}{\pi} = 16.43$$

$$k := \sqrt{1 - (x)^2} + \left(\frac{2}{\pi} - \frac{\pi}{2} \right) x \quad 100 \cdot k = 69.49$$

$$I_{pk} := \frac{I_{dc}}{k} \quad I_{pk} = 35.97$$

$$L_{cr} := \frac{V_m}{\omega \cdot I_{pk}} \quad 1000 \cdot L_{cr} = 12.51 \quad \text{mH}$$

$$k_T := \sqrt{\frac{1}{\pi} \cdot \int_{\alpha}^{\alpha+\pi} [(\cos(\alpha) - \cos(\phi)) - x \cdot (\phi - \alpha)]^2 d\phi}$$

$$100 \cdot k_T = 81.91$$

$$I_{rms} := k_T \cdot I_{pk} \quad I_{rms} = 29.47$$

(b)

$$I_{dc} := 15 \quad I_{pk} := 69.25$$

$$k := \frac{100 \cdot I_{dc}}{I_{pk}} \quad k = 21.66$$

$$x_n := 60 \quad x_{n1} := 65$$

$$\alpha_n := 36.87 \quad \alpha_{n1} := 40.54$$

$$k_n := 23.95 \quad k_{n1} := 15.27$$

$$kr_n := 31.05 \quad kr_{n1} := 26.58$$

$$x := x_n + \left[\frac{(x_{n1} - x_n) \cdot (k - k_n)}{k_{n1} - k_n} \right] \quad x = 61.32$$

$$V_{dc} := x \cdot \frac{V_m}{100} \quad V_{dc} = 104.06$$

$$\alpha := \alpha_n + \left[\frac{(\alpha_{n1} - \alpha_n) \cdot (k - k_n)}{k_{n1} - k_n} \right] \quad \alpha = 37.84$$

$$kr := kr_n + \left[\frac{(kr_{n1} - kr_n) \cdot (k - k_n)}{k_{n1} - k_n} \right] \quad kr = 29.87$$

$$I_{rms} := \frac{kr \cdot I_{pk}}{100} \quad I_{rms} = 20.69$$

Problem 3-17

Let t_1 and t_2 be the charging and discharging time of capacitor. For a single-phase full-wave rectifier, the period of output voltage is $T/2$, where T is the period of the input voltage and the supply frequency is $f = 1/T$.

$t_1 + t_2 = T/2$. If $t_2 \gg t_1$ which is normally the case, $t_2 \approx T/2$

During discharging of the capacitor, the capacitor discharges exponentially and the output (or capacitor) voltage is

$$v_o(t) = V_m e^{-t/RC}$$

where V_m is the peak value of supply voltage.

The peak-to-peak ripple voltage is

$$v_r = v_o(t=t_1) - v_o(t=t_2) = V_m - V_m e^{-t_2/RC} = V_m [1 - e^{-t_2/RC}]$$

Since, $e^{-x} \approx 1 - x$, $v_r = V_m (1 - 1 + t_2/RC) = V_m t_2/RC = V_m/(2fRC)$

Thus, the rms value of the output voltage harmonics is

$$V_{ac} = \frac{v_r}{2\sqrt{2}} = \frac{V_m}{4\sqrt{2} f RC}$$

Problem 3-18

$R = 20 \Omega$, $L = 5 \text{ mH}$, $f = 60 \text{ Hz}$, $\omega = 2\pi f = 377 \text{ rad/s}$

Taking a ratio of 10:1, the value of the capacitor is given by

$$\sqrt{R^2 + (6\omega L)^2} = \frac{10}{6\omega C_e}$$

or
$$C_e = \frac{10}{6 \times 377 \sqrt{R^2 + (6 \times 377 L)^2}} = 192.4 \mu\text{F}$$

From Eq. (3-39), the rms value of the 6th harmonic is

$$V_6 = \frac{2}{35\sqrt{2}} \times 0.9549 V_m$$

From Eq. (3-64), the rms value of the ripple voltage is

$$V_{ac} = \frac{V_6}{(n\omega)^2 L_1 C - 1} = \frac{2}{35\sqrt{2}} \times \frac{0.9549 V_m}{(6\omega)^2 L_1 C - 1}$$

$$V_{dc} = 0.9549 V_m$$

The ripple factor is

$$RF = \frac{V_{ac}}{V_{dc}} = \frac{\sqrt{2}}{35} \times \frac{1}{(6\omega)^2 L_1 C - 1} = 0.05$$

or $(6\omega)^2 L_1 C - 1 = 0.808$ and $L_1 = 1.837$ mH

Problem 3-19

(a) With $q = 6$, Eq. (3-39) gives the output voltage as

$$v_L(t) = 0.9549 V_m \left[1 + \frac{2}{35} \cos(6\omega t) - \frac{2}{143} \cos(12\omega t) + \dots \right]$$

The load impedance, $Z = R + j(n\omega L) = \sqrt{R^2 + (n\omega L)^2} \angle \theta_n$

$$\text{and } \theta_n = \tan^{-1}(n\omega L / R)$$

and the load current is

$$i_L(t) = I_{dc} - \frac{0.9549 V_m}{\sqrt{R^2 + (n\omega L)^2}} \left[\frac{2}{35} \cos(6\omega t - \theta_6) - \frac{2}{143} \cos(12\omega t - \theta_{12}) + \dots \right]$$

where
$$I_{dc} = \frac{V_{dc}}{R} = \frac{0.9549 V_m}{R}$$

(b) $V_m = 170$ V, $f = 60$ Hz, $R = 200 \Omega$, $\omega = 2\pi f = 377$ rad/s

The rms value of the ripple current is

$$I_{ac}^2 = \frac{(0.9549 V_m)^2}{2[R^2 + (6\omega L)^2]} \left(\frac{2}{35} \right)^2 + \frac{(0.9549 V_m)^2}{2[R^2 + (12\omega L)^2]} \left(\frac{2}{143} \right)^2 + \dots$$

Considering only the lowest order harmonic ($n = 6$) and neglecting others,

$$I_{ac} = \frac{0.9549 V_m}{\sqrt{2} \sqrt{R^2 + (6\omega L)^2}} \left(\frac{2}{35} \right)$$

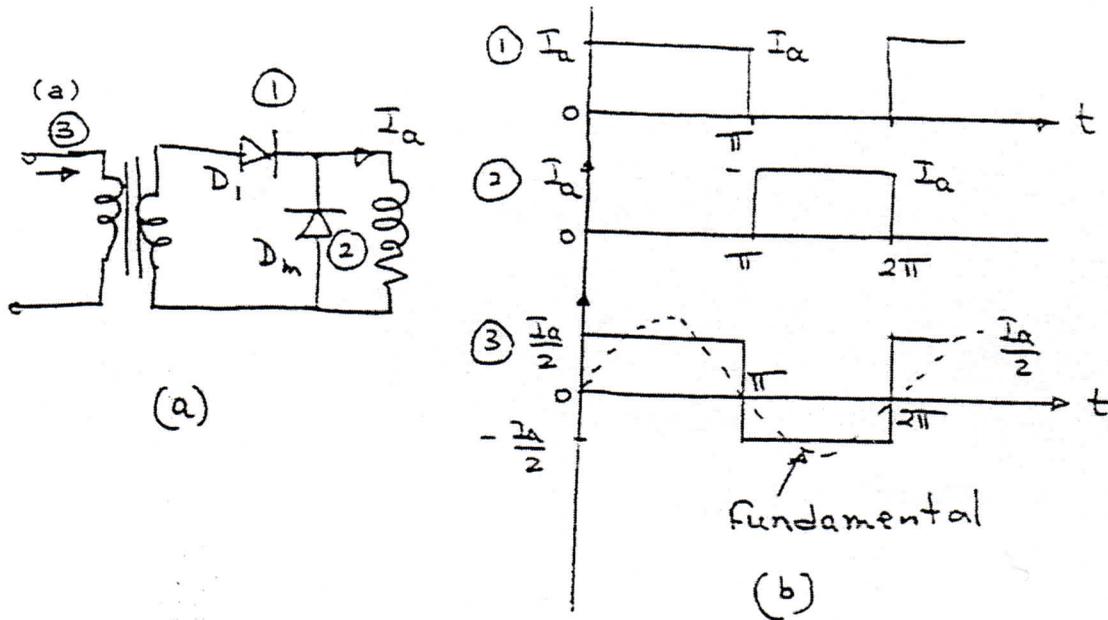
Using the value of I_{dc} and after simplification, the ripple factor is

$$RF = \frac{I_{ac}}{I_{dc}} = \frac{1}{\sqrt{2} \times \sqrt{1 + (6\omega L / R)^2}} \left(\frac{2}{35} \right) = 0.02$$

$$0.0404^2 = 0.02^2 [1 + (6 \times 377 L / 200)^2] \text{ or } L = 11.64 \text{ mH}$$

Problem 3-20

(a)



(b) For the primary (or supply) current,

$$a_0 = 0$$

$$a_n = \frac{1}{\pi} \int_0^{2\pi} \frac{I_a}{2} \cos(n\theta) d\theta = 0$$

$$b_n = \frac{1}{\pi} \int_0^{2\pi} \frac{I_a}{2} \sin(n\theta) d\theta = \frac{2I_a}{n\pi}$$

$$\phi_n = \tan^{-1} (a_n/b_n) = 0$$

$$i_s(t) = \frac{2I_a}{\pi} \left[\frac{\sin \omega t}{1} + \frac{\sin 3\omega t}{3} + \frac{\sin 5\omega t}{5} + \dots \right]$$

The rms value of the fundamental current is

$$I_1 = 2I_a/(\pi\sqrt{2})$$

The rms current is $I_s = I_a/2$. At the primary (or supply) side, $PF = I_1/I_s =$

$$2\sqrt{2}/\pi = 0.9 \text{ and } HF = \sqrt{(I_1/I_s)^2 - 1} = 0.4834.$$

(c) For the rectifier input (or secondary) side,

$$a_0/2 = I_a/2$$

$$a_n = \frac{1}{\pi} \int_0^{\pi} I_a \cos(n\theta) d\theta = 0$$

$$b_n = \frac{1}{\pi} \int_0^{\pi} I_a \sin(n\theta) d\theta = \frac{I_a}{n\pi} (1 - \cos n\theta)$$

$$\phi_n = \tan^{-1} (a_n/b_n) = 0$$

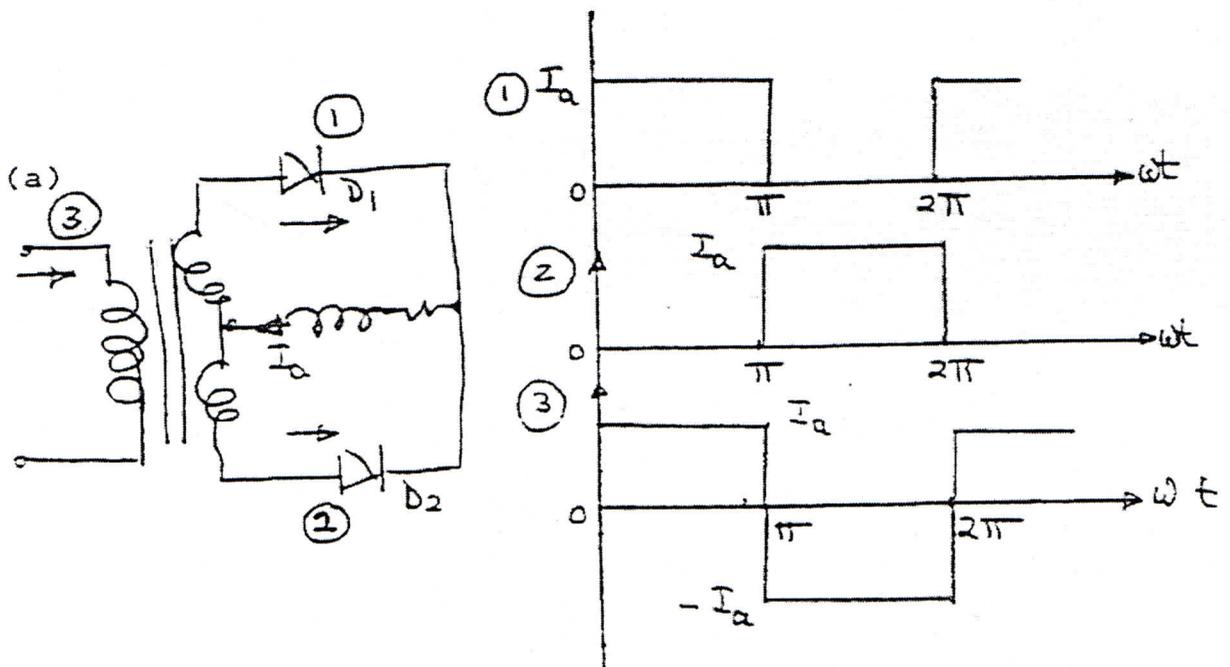
$$C_n = \sqrt{(a_n^2 + b_n^2)} \text{ and } I_1 = C_1/\sqrt{2} = \sqrt{2}I_a/\pi$$

$$\text{and } I_s = I_a/\sqrt{2}$$

$$\text{PF} = I_1/I_s = 2/\pi = 0.6366 \text{ and } \text{HF} = \sqrt{(I_s/I_1)^2 - 1} = 1.211$$

Problem 3-21

(a)



(b) For the primary (or supply) current: From Eq. (3-23), the primary current is

$$i_s(t) = \frac{4I_a}{\pi} \left[\frac{\sin \omega t}{1} + \frac{\sin 3\omega t}{3} + \frac{\sin 5\omega t}{5} + \dots \right]$$

$$I_1 = 4I_a / (\pi\sqrt{2})$$

The rms current is $I_s = I_a$. $PF = I_1/I_s = 2\sqrt{2}/\pi = 0.9$ and $HF = \sqrt{(I_s/I_1)^2 - 1} = 0.4834$.

(c) For the rectifier input (or secondary) current:

$$a_0/2 = I_a/2$$

$$a_n = \frac{1}{\pi} \int_0^\pi I_a \cos(n\theta) d\theta = 0$$

$$b_n = \frac{1}{\pi} \int_0^\pi I_a \sin(n\theta) d\theta = \frac{I_a}{n\pi} (1 - \cos n\theta)$$

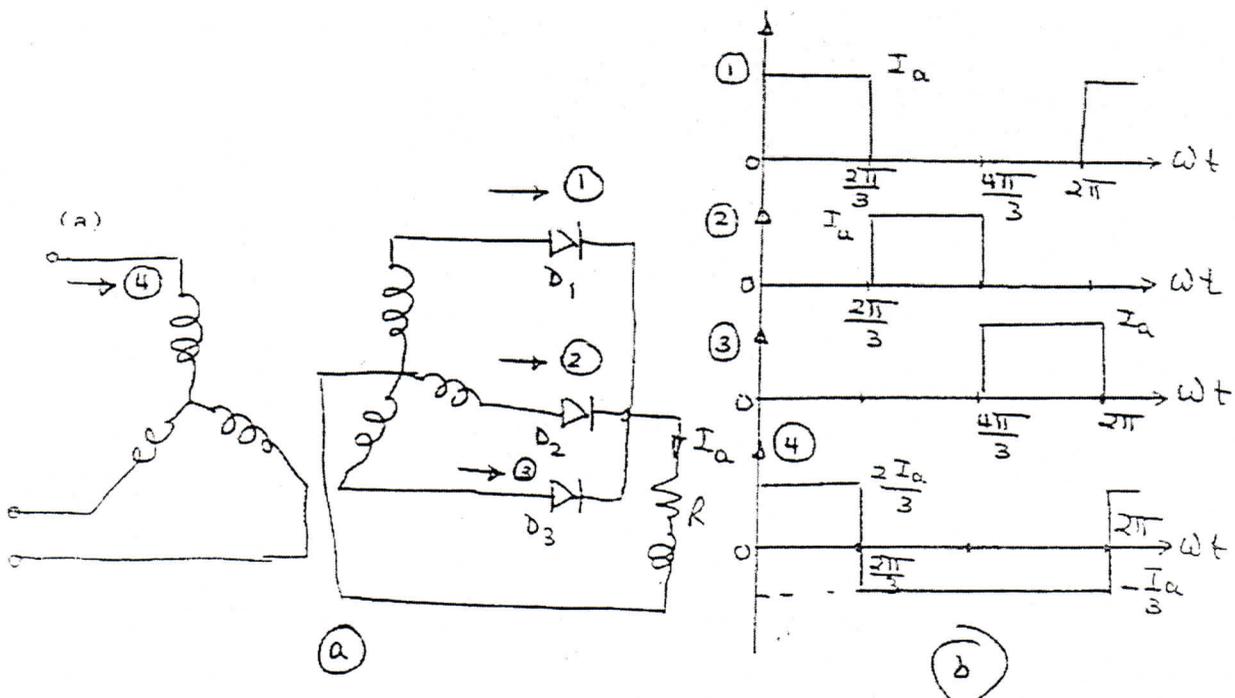
$$\phi_n = \tan^{-1} (a_n/b_n) = 0$$

$$C_n = \sqrt{(a_n^2 + b_n^2)} \text{ and } I_1 = C_1/\sqrt{2} = \sqrt{2}I_a/\pi$$

$$\text{and } I_s = I_a/\sqrt{2}$$

$$PF = I_1/I_s = 2/\pi = 0.6366 \text{ and } HF = \sqrt{(I_s/I_1)^2 - 1} = 1.211$$

Problem 3-22 (a)



(b) For the primary (or secondary) phase (or line) current:

$$a_0/2 = 0$$

$$a_n = \frac{1}{\pi} \int_{\pi/6}^{5\pi/6} \frac{2I_a}{3} \cos(n\theta) d\theta - \frac{1}{\pi} \int_{5\pi/6}^{2\pi+\pi/6} \frac{I_a}{3} \cos(n\theta) d\theta$$

$$= \frac{2I_a}{n\pi} \cos \frac{n\pi}{2} \sin \frac{n\pi}{3}$$

$$b_n = \frac{1}{\pi} \int_{\pi/6}^{5\pi/6} \frac{2I_a}{3} \sin(n\theta) d\theta - \frac{1}{\pi} \int_{5\pi/6}^{2\pi+\pi/6} \frac{I_a}{3} \sin(n\theta) d\theta$$

$$= \frac{2I_a}{n\pi} \sin \frac{n\pi}{2} \sin \frac{n\pi}{3}$$

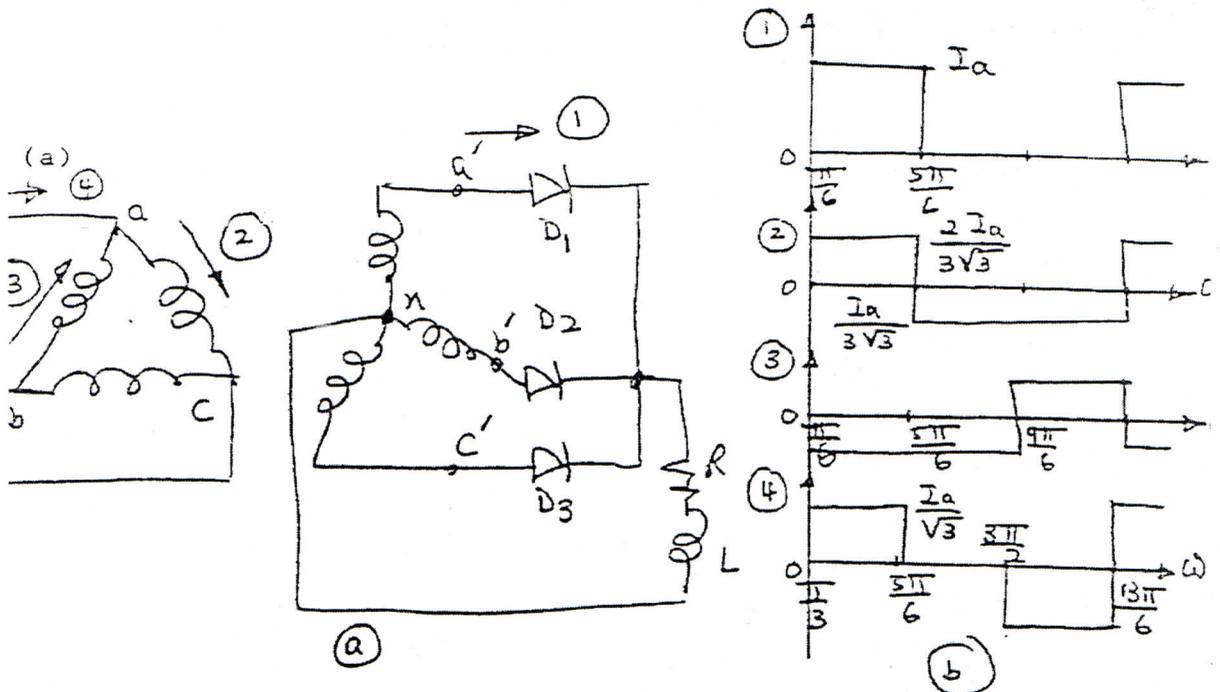
$$C_n = \sqrt{a_n^2 + b_n^2} = \frac{2I_a}{n\pi} \sin \frac{n\pi}{3}$$

$$\varphi_n = \tan^{-1} (a_n/b_n) = \tan^{-1} (\cot n\pi/2)$$

(c) $I_1 = C_1/\sqrt{2} = \sqrt{3}I_a/(\pi\sqrt{2})$, $\varphi_1 = 0$ and $I_s = \sqrt{2} I_a/3$

$$PF = I_1/I_s = 3\sqrt{3}/2\pi = 0.827 \text{ and } HF = \sqrt{(I_s/I_1)^2 - 1} = 0.68$$

Problem 3-23 (a)



(b) For the primary line current:

$$a_0/2 = 0$$

$$\begin{aligned} a_n &= \frac{1}{\pi} \int_{\pi/6}^{\pi/6} \frac{I_a}{\sqrt{3}} \cos(n\theta) d\theta - \frac{1}{\pi} \int_{5\pi/2}^{2\pi+\pi/6} \frac{I_a}{\sqrt{3}} \cos(n\theta) d\theta \\ &= -\frac{2I_a}{\sqrt{3}n\pi} \sin \frac{n\pi}{6} (1 - \cos \frac{2n\pi}{3}) \end{aligned}$$

$$\begin{aligned} b_n &= \frac{1}{\pi} \int_{\pi/6}^{\pi/6} \frac{I_a}{\sqrt{3}} \sin(n\theta) d\theta - \frac{1}{\pi} \int_{5\pi/2}^{2\pi+\pi/6} \frac{I_a}{\sqrt{3}} \sin(n\theta) d\theta \\ &= \frac{2I_a}{\sqrt{3}n\pi} \cos \frac{n\pi}{6} (1 - \cos \frac{2n\pi}{3}) \end{aligned}$$

$$C_n = \sqrt{a_n^2 + b_n^2} = \frac{2I_a}{\sqrt{3}n\pi} (1 - \cos \frac{2n\pi}{3})$$

$$\varphi_n = \tan^{-1} (a_n/b_n) = \tan^{-1} (-\tan n\pi/6) = -n\pi/6$$

$$I_1 = C_1/\sqrt{2} = \sqrt{3}I_a/(\pi\sqrt{2}), \varphi_1 = -\pi/6 \text{ and } I_s = \sqrt{2} I_a/3$$

(c) For the secondary (or primary) phase current,

$$a_0/2 = 0$$

$$\begin{aligned} a_n &= \frac{1}{\pi} \int_{\pi/6}^{\pi/6} \frac{2I_a}{3\sqrt{3}} \cos(n\theta) d\theta - \frac{1}{\pi} \int_{5\pi/6}^{2\pi+\pi/6} \frac{I_a}{3\sqrt{3}} \cos(n\theta) d\theta \\ &= \frac{2I_a}{\sqrt{3}n\pi} \cos \frac{n\pi}{2} \sin \frac{n\pi}{3} \end{aligned}$$

$$\begin{aligned} b_n &= \frac{1}{\pi} \int_{\pi/6}^{\pi/6} \frac{2I_a}{3\sqrt{3}} \sin(n\theta) d\theta - \frac{1}{\pi} \int_{5\pi/6}^{2\pi+\pi/6} \frac{I_a}{3\sqrt{3}} \sin(n\theta) d\theta \\ &= \frac{2I_a}{\sqrt{3}n\pi} \sin \frac{n\pi}{2} \sin \frac{n\pi}{3} \end{aligned}$$

$$C_n = \sqrt{a_n^2 + b_n^2} = \frac{2I_a}{3n\pi} \sin \frac{n\pi}{3}$$

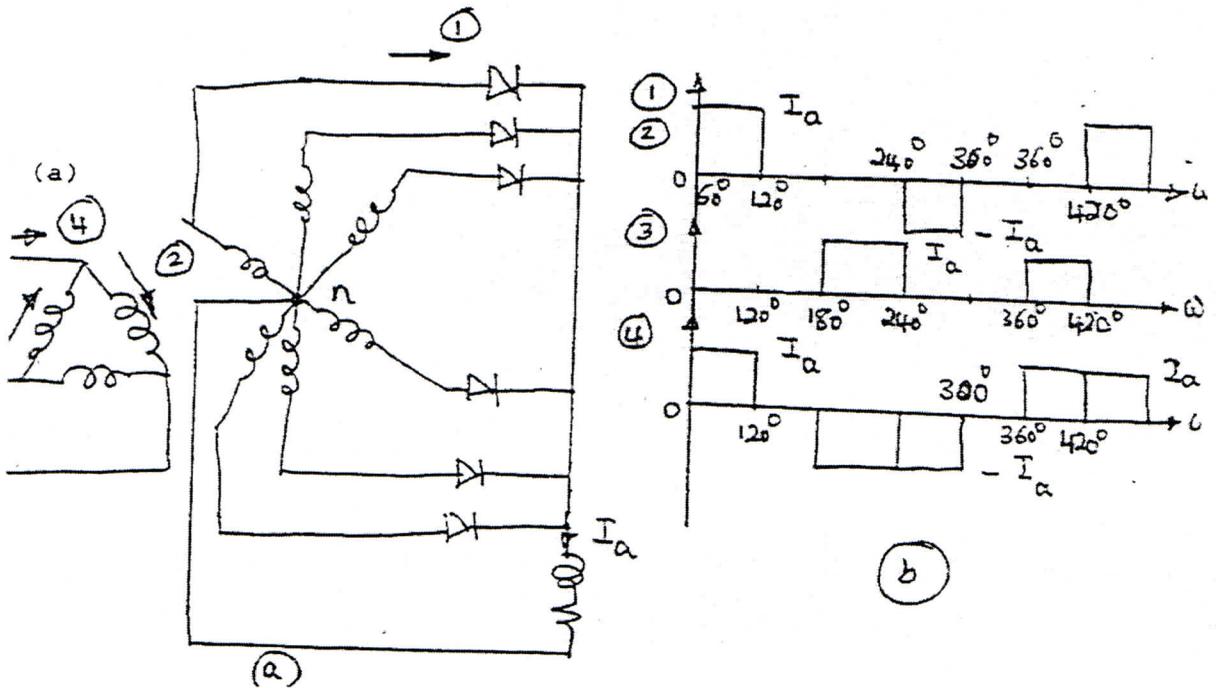
$$\varphi_n = \tan^{-1} (a_n/b_n) = \tan^{-1} (\cot n\pi/2) = n\pi/2$$

$$I_1 = C_1/\sqrt{2} = I_a/(\pi\sqrt{2}), \varphi_1 = 0 \text{ and } I_s = \sqrt{2} I_a/(3\sqrt{3})$$

$$PF = I_1/I_s = 3\sqrt{3}/2\pi = 0.827 \text{ and } HF = \sqrt{(I_s/I_1)^2 - 1} = 0.68$$

Problem 3-24

(a)



(b) For the primary line current:

$$a_0/2 = 0$$

$$a_n = \frac{I_a}{\pi} \left[\int_{\pi/3}^{2\pi/3} \cos(n\theta) d\theta - \int_{\pi}^{5\pi/3} \cos(n\theta) d\theta + \int_{2\pi}^{2\pi+\pi/3} \cos(n\theta) d\theta \right]$$

$$= -\frac{2I_a}{n\pi} \sin \frac{n\pi}{2} \cos \frac{7n\pi}{6}$$

$$b_n = \frac{I_a}{\pi} \left[\int_{\pi/3}^{2\pi/3} \sin(n\theta) d\theta - \int_{\pi}^{5\pi/3} \sin(n\theta) d\theta + \int_{2\pi}^{2\pi+\pi/3} \sin(n\theta) d\theta \right]$$

$$= \frac{I_a}{n\pi} \left(1 - \cos n\pi - 2 \sin \frac{n\pi}{2} \cos \frac{7n\pi}{6} \right)$$

$$\text{For } n = 1, C_1 = \sqrt{(a_1^2 + b_1^2)} = 2\sqrt{3}I_a/\pi$$

$$\phi_1 = \tan^{-1} (a_1/b_1) = \tan^{-1}(1/\sqrt{3}) = \pi/6$$

$$I_1 = C_1/2 = \sqrt{2} \sqrt{3} I_a / \pi, \text{ and } I_s = I_a \sqrt{(2/3)}$$

(c) For the secondary or primary phase current,

$$a_0/2 = 0$$

$$a_n = \frac{I_a}{\pi} \left[\int_{\pi/3}^{2\pi/3} \cos(n\theta) d\theta - \int_{4\pi/3}^{5\pi/3} \cos(n\theta) d\theta \right] = 0$$

$$b_n = \frac{I_a}{\pi} \left[\int_{\pi/3}^{2\pi/3} \sin(n\theta) d\theta - \int_{4\pi/3}^{5\pi/3} \sin(n\theta) d\theta \right]$$

$$= \frac{4I_a}{n\pi} \sin \frac{n\pi}{2} \sin \frac{n\pi}{6}$$

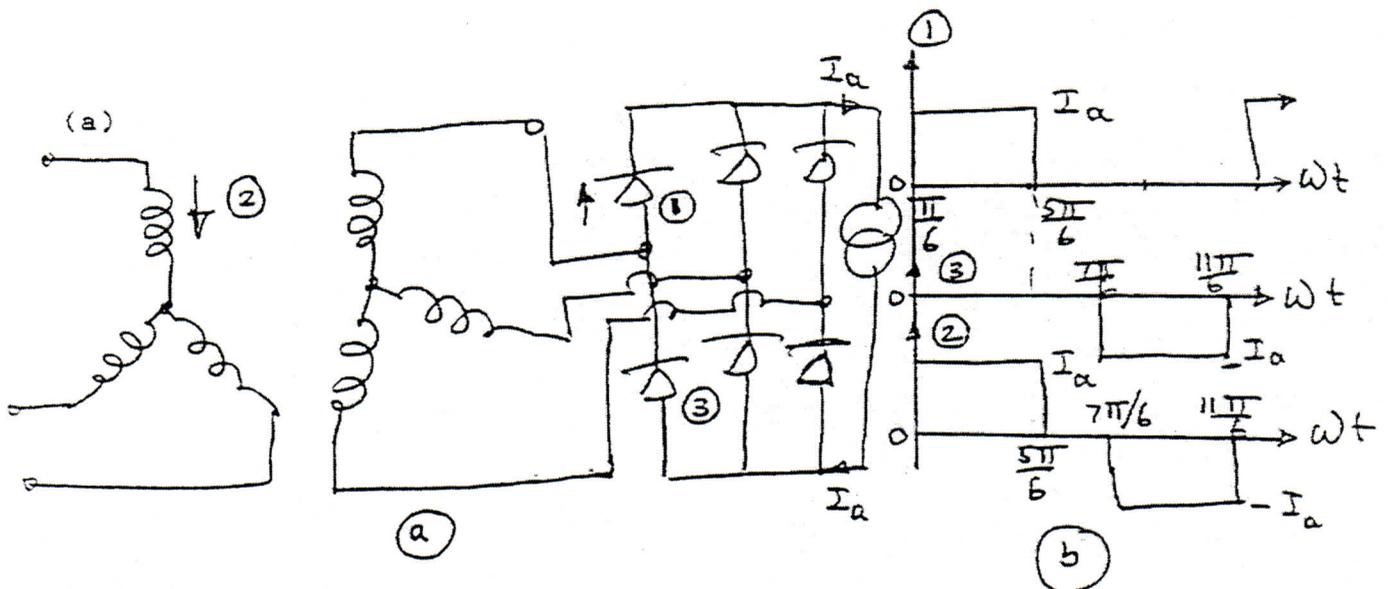
$$C_n = b_n \text{ and } \varphi_n = 0$$

$$C_1 = 2 I_a / \pi, I_1 = C_1 / \sqrt{2} = 2 I_a / (\sqrt{2} \pi), \varphi_1 = 0 \text{ and } I_s = I_a / \sqrt{3}$$

$$\text{PF} = I_1 / I_s = \sqrt{2} \sqrt{3} / \pi = 0.78 \text{ and } \text{HF} = \sqrt{(I_s / I_1)^2 - 1} = 0.803$$

Problem 3-25

(a)



(b) For the primary (or secondary) phase (or line) current:

$$a_0/2 = 0$$

$$a_n = \frac{2I_a}{\pi} \int_{\pi/6}^{\pi/2} \cos(n\theta) d\theta = \frac{4I_a}{n\pi} \sin \frac{n\pi}{3} \cos \frac{n\pi}{2}$$

$$b_n = \frac{2I_a}{\pi} \int_{\pi/6}^{\pi/2} \sin(n\theta) d\theta = \frac{4I_a}{n\pi} \sin \frac{n\pi}{3} \sin \frac{n\pi}{2}$$

$$C_n = \frac{4I_a}{n\pi} \sin \frac{n\pi}{3} \text{ and } \varphi_n = \tan^{-1} (a_n/b_n) = \tan^{-1}(\cot n\pi/2)$$

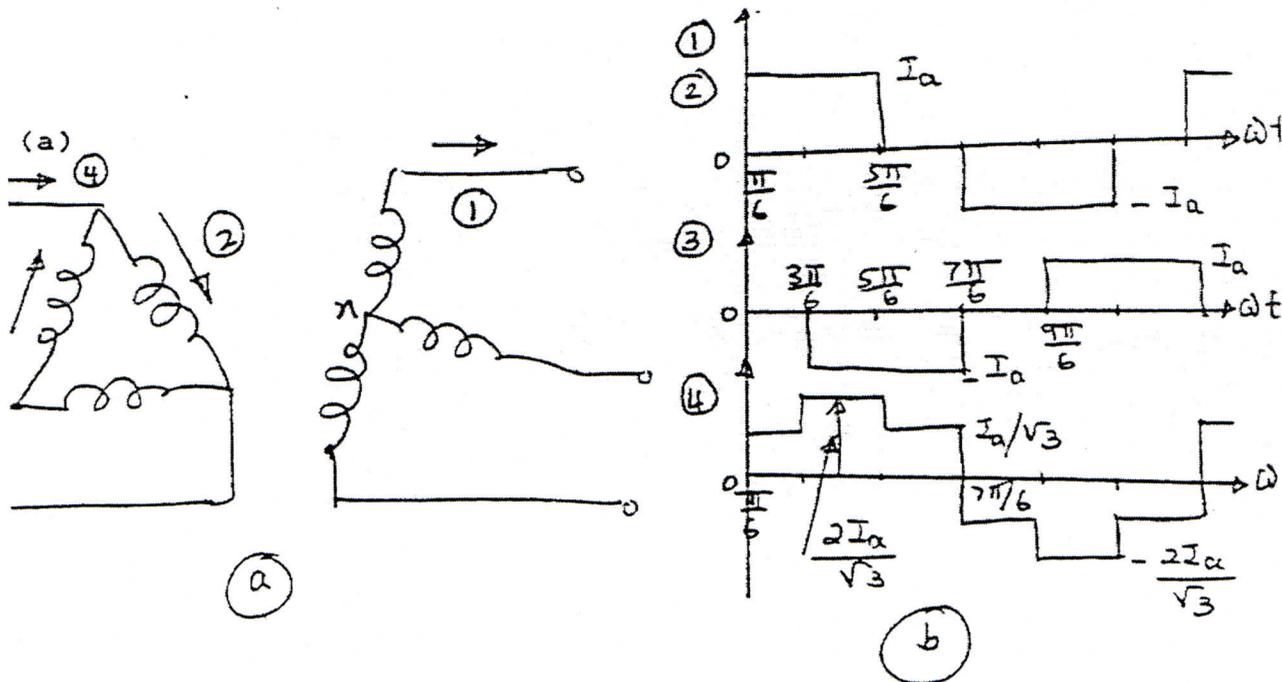
$$(c) C_1 = 2\sqrt{3}I_a/\pi \text{ and } \varphi_1 = 0$$

$$I_1 = C_1/\sqrt{2} = \sqrt{2} \sqrt{3}I_a/\pi, \text{ and } I_s = I_a \sqrt{(2/3)}$$

$$PF = I_1/I_s = 3/\pi = 0.9549 \text{ and } HF = \sqrt{(I_s/I_1)^2 - 1} = 0.3108$$

Problem 3-26

(a)



(b) For the primary line current,

$$a_0/2 = 0$$

$$a_n = \frac{2I_a}{\sqrt{3}\pi} \left[\int_{\pi/6}^{\pi/2} \cos(n\theta) d\theta + \int_{\pi/2}^{5\pi/6} 2 \cos(n\theta) d\theta + \int_{5\pi/6}^{7\pi/6} \cos(n\theta) d\theta \right]$$

$$= -\frac{8I_a}{\sqrt{3}n\pi} \cos \frac{2n\pi}{3} \sin \frac{n\pi}{3} \cos \frac{n\pi}{6}$$

$$b_n = \frac{2I_a}{\sqrt{3}\pi} \left[\int_{\pi/6}^{\pi/2} \sin(n\theta) d\theta + \int_{\pi/2}^{5\pi/6} 2 \sin(n\theta) d\theta + \int_{5\pi/6}^{7\pi/6} \sin(n\theta) d\theta \right]$$

$$= \frac{8I_a}{\sqrt{3}n\pi} \sin \frac{2n\pi}{3} \sin \frac{n\pi}{3} \cos \frac{n\pi}{6}$$

$$C_n = \frac{8I_a}{\sqrt{3}n\pi} \sin \frac{n\pi}{3} \cos \frac{n\pi}{6}$$

$$\varphi_n = \tan^{-1} (a_n/b_n) = \tan^{-1}(\cot(2n\pi/3))$$

$$C_1 = 2\sqrt{3}I_a/\pi \text{ and } I_1 = C_1/\sqrt{2} = \sqrt{2} \sqrt{3}I_a/\pi, \varphi_1 = \tan^{-1} (-1/\sqrt{3}) = -\pi/6$$

(c) For the primary (or secondary) phase current,

$$a_0/2 = 0$$

$$a_n = \frac{2I_a}{\pi} \int_{\pi/6}^{5\pi/6} \cos(n\theta) d\theta = \frac{4I_a}{n\pi} \sin \frac{n\pi}{3} \cos \frac{n\pi}{2}$$

$$b_n = \frac{2I_a}{\pi} \int_{\pi/6}^{5\pi/6} \sin(n\theta) d\theta = \frac{4I_a}{n\pi} \sin \frac{n\pi}{3} \sin \frac{n\pi}{2}$$

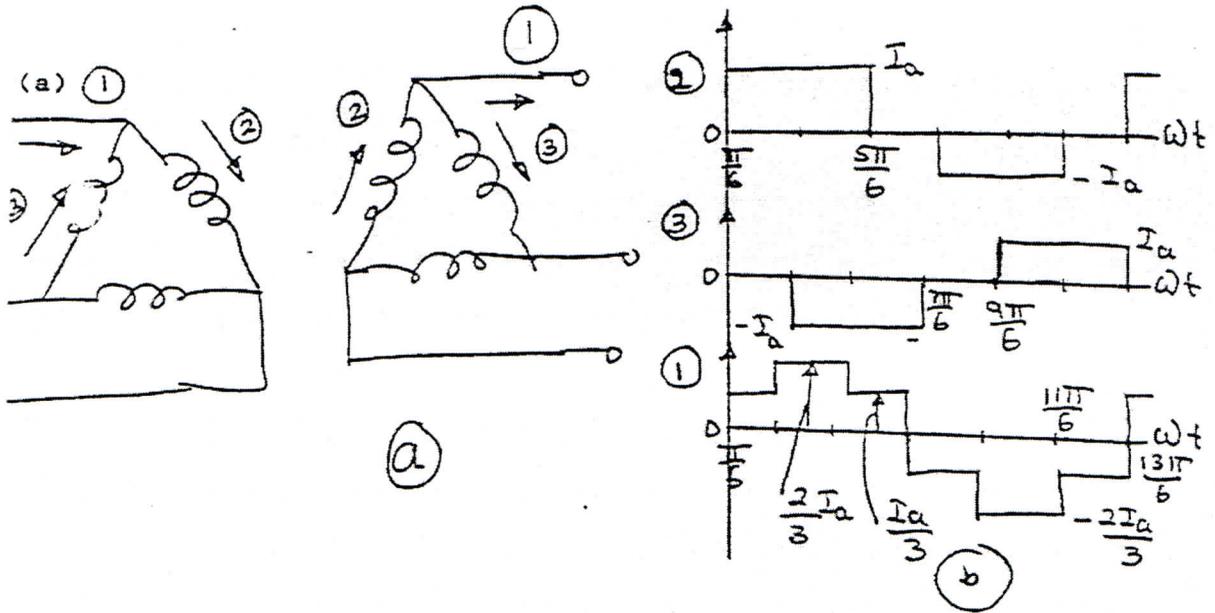
$$C_n = \frac{4I_a}{n\pi} \sin \frac{n\pi}{3} \text{ and } \varphi_n = \tan^{-1} (a_n/b_n) = \tan^{-1}(\cot n\pi/2)$$

$$I_1 = C_1/\sqrt{2} = \sqrt{2} \sqrt{3}I_a/\pi, \text{ and } I_s = I_a \sqrt{(2/3)}$$

$$\text{PF} = I_1/I_s = 3/\pi = 0.9549 \text{ and } \text{HF} = \sqrt{(I_s/I_1)^2 - 1} = 0.3108$$

Problem 3-27

(a)



(b) For the primary (or secondary) line current,

$$a_0/2 = 0$$

$$a_n = \frac{2I_a}{\pi} \int_{\pi/6}^{\pi/2} \cos(n\theta) d\theta = \frac{4I_a}{n\pi} \sin \frac{n\pi}{3} \cos \frac{n\pi}{2}$$

$$b_n = \frac{2I_a}{\pi} \int_{\pi/6}^{\pi/2} \sin(n\theta) d\theta = \frac{4I_a}{n\pi} \sin \frac{n\pi}{3} \sin \frac{n\pi}{2}$$

$$C_n = \frac{4I_a}{n\pi} \sin \frac{n\pi}{3} \text{ and } \phi_n = \tan^{-1} (a_n/b_n) = \tan^{-1}(\cot n\pi/2)$$

$$I_1 = C_1/\sqrt{2} = \sqrt{2} \sqrt{3}I_a/\pi, \text{ and } I_s = I_a \sqrt{(2/3)}$$

(c) For the primary (or secondary) phase current,

$$a_0/2 = 0$$

$$a_n = \frac{2I_a}{3\pi} \left[\int_{\pi/6}^{\pi/2} \cos(n\theta) d\theta + \int_{\pi/2}^{\pi/3} 2 \cos(n\theta) d\theta + \int_{\pi/3}^{\pi/6} \cos(n\theta) d\theta \right]$$

$$= \frac{8I_a}{3n\pi} \cos \frac{2n\pi}{3} \sin \frac{n\pi}{3} \cos \frac{n\pi}{6}$$

$$b_n = \frac{2I_a}{3\pi} \left[\int_{\pi/6}^{\pi/2} \sin(n\theta) d\theta + \int_{\pi/2}^{5\pi/6} 2 \sin(n\theta) d\theta + \int_{5\pi/6}^{7\pi/6} \sin(n\theta) d\theta \right]$$

$$= \frac{8I_a}{3n\pi} \sin \frac{2n\pi}{3} \sin \frac{n\pi}{3} \cos \frac{n\pi}{6}$$

$$C_n = \frac{8I_a}{3n\pi} \sin \frac{n\pi}{3} \cos \frac{n\pi}{6}$$

$$\varphi_n = \tan^{-1} (a_n/b_n) = \tan^{-1}(\cot(2n\pi/3))$$

$$C_1 = 2\sqrt{3}I_a/\pi \text{ and } I_1 = C_1/\sqrt{2} = \sqrt{2} \sqrt{3}I_a/\pi, \varphi_1 = \tan^{-1} (-1/\sqrt{3}) = -\pi/6$$

$$I_s = \sqrt{2}I_a/3, \text{ PF} = I_1/I_s = 3/\pi = 0.9549$$

$$\text{HF} = [(I_s/I_1)^2 - 1]^{1/2} = 0.3108$$

CHAPTER 4
POWER TRANSISTORS

Problem 4-1

$V_{CC} = 100 \text{ V}$, $\beta_{\min} = 10$, $\beta_{\max} = 60$, $R_C = 5 \Omega$, $ODF = 20$, $V_B = 8 \text{ V}$,
 $V_{CE(\text{sat})} = 2.5 \text{ V}$ and $V_{BE(\text{sat})} = 1.75 \text{ V}$.

From Eq. (4-14), $I_{CS} = (100 - 2.5)/5 = 19.5 \text{ A}$

From Eq. (4-15), $I_{BS} = 19.5/\beta_{\min} = 19.5/10 = 1.95 \text{ A}$

Eq. (4-16) gives the base current for a overdrive factor of 20,

$$I_B = 20 \times 1.95 = 33 \text{ A}$$

(a) Eq. (4-9) gives the required value of R_B ,

$$R_B = (V_B - V_{BE(\text{sat})})/I_B = (8 - 1.75)/33 = 0.1894 \Omega$$

(b) From Eq. (4-17), $\beta_f = 19.5/33 = 0.59$

(c) Eq. (4-18) yields the total power loss as

$$P_T = 1.75 \times 33 + 2.5 \times 19.5 = 106.5 \text{ W}$$

Problem 4-2

$V_{CC} = 40 \text{ V}$, $\beta_{\min} = 12$, $\beta_{\max} = 75$, $R_C = 1.5 \Omega$, $V_B = 6 \text{ V}$,
 $V_{CE(\text{sat})} = 1.2 \text{ V}$ and $V_{BE(\text{sat})} = 1.6 \text{ V}$.

From Eq. (4-14), $I_{CS} = (40 - 1.2)/1.5 = 25.87 \text{ A}$

From Eq. (4-15), $I_{BS} = 25.87/\beta_{\min} = 25.87/12 = 2.156 \text{ A}$

$$I_B = (6 - 1.6)/0.7 = 4.4/0.7 = 6.286 \text{ A}$$

(a) $ODF = I_B/I_{BS} = 6.286/2.156 = 2.916$

(b) From Eq. (4-17), $\beta_f = 25.8/6.286 = 4.104$

(c) Eq. (4-18) yields the total power loss as

$$P_T = 1.2 \times 25.87 + 1.6 \times 6.286 = 41.104 \text{ W}$$

Problem 4-3

$V_{CC} = 200 \text{ V}$, $B_{BE(\text{sat})} = 3 \text{ V}$, $I_B = 8 \text{ A}$, $V_{CE(\text{sat})} = 2 \text{ V}$, $I_{CS} = 100 \text{ A}$, $t_d = 0.5 \mu\text{s}$, $t_r = 1 \mu\text{s}$, $t_s = 5 \mu\text{s}$, $t_f = 3 \mu\text{s}$, $f_s = 10 \text{ kHz}$, $k = 0.5$, $T = 1/f_s = 100 \mu\text{s}$. $kT = t_d + t_r + t_n = 50 \mu\text{s}$ and $t_n = 50 - 0.5 - 1 = 48.5 \mu\text{s}$, $(1-k)T = t_s + t_f + t_o = 50 \mu\text{s}$ and $t_o = 50 - 5 - 3 = 42 \mu\text{s}$.

(a) From Eq. (4-21),

$$P_c(t) = 3 \times 10^{-3} \times 200 = 0.6 \text{ W}$$

$$P_d = 3 \times 10^{-3} \times 200 \times 0.5 \times 10^{-6} \times 10 \times 10^3 = 3 \text{ mW}$$

During rise time, $0 \leq t \leq t_r$:

$$\text{From Eq. (4-23), } t_m = 1 \times 200 / [2(200 - 2)] = 0.505 \mu\text{s}$$

$$\text{From Eq. (4-24), } P_p = 200^2 \times 100 / [4(200 - 2)] = 5050.5 \text{ W}$$

From Eq. (4-25),

$$P_r = 10 \times 10^3 \times 100 \times 1 \times 10^{-6} [220/2 + (2 - 200)/3] = 34 \text{ W}$$

$$P_{on} = P_d + P_r = 0.003 + 34 = 34.003 \text{ W}$$

(b) Conduction Period, $0 \leq t \leq t_n$:

$$P_c(t) = 2 \times 100 = 200 \text{ W}$$

$$\text{From Eq. (4-27), } P_n = 2 \times 100 \times 48.5 \times 10^{-6} \times 10 \times 10^3 = 97 \text{ W}$$

(c) Storage Period, $0 \leq t \leq t_s$:

$$P_c(t) = 2 \times 100 = 200 \text{ W}$$

$$\text{From Eq. (4-28), } P_s = 2 \times 100 \times 5 \times 10^{-6} \times 10 \times 10^3 = 10 \text{ W}$$

Fall time, $0 \leq t \leq t_f$:

$$\text{From Eq. (4-30), } P_p = 200 \times 100 / 4 = 5000 \text{ W}$$

$$\text{From Eq. (4-31), } P_f = 200 \times 100 \times 3 \times 10^{-6} \times 10 \times 10^3 / 6 = 100 \text{ W}$$

$$P_{off} = P_s + P_f = 10 + 100 = 110 \text{ W}$$

(d) Off-period, $0 \leq t \leq t_o$:

$$P_c(t) = 3 \times 10^{-3} \times 200 = 0.6 \text{ W}$$

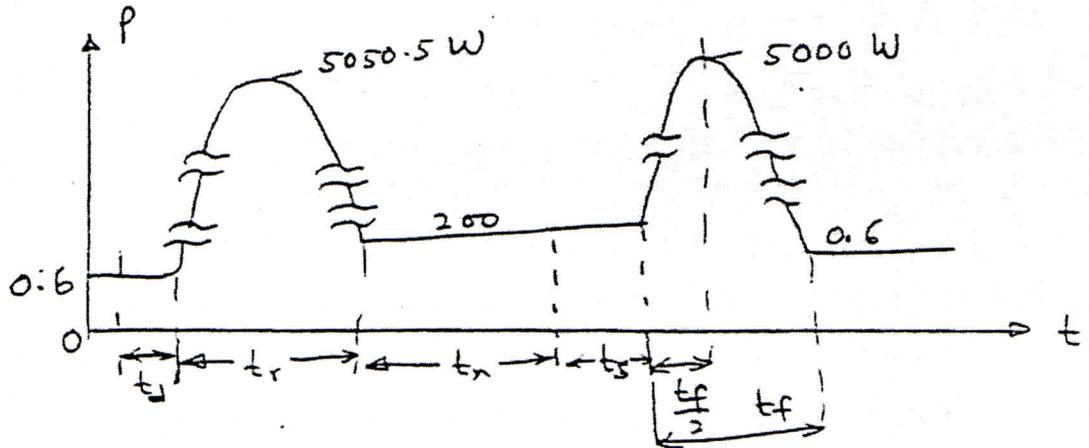
From Eq. (4-33),

$$P_o = 3 \times 10^{-3} \times 200 \times 42 \times 10^{-6} \times 10 \times 10^3 = 0.252 \text{ W}$$

(e) The total power loss in the transistor due to collector current is

$$P_T = P_{on} + P_n + P_{off} + P_o = 34.003 + 97 + 110 + 241.255 \text{ W}$$

(f)



Problem 4-4

$$T_J = 150 \text{ }^\circ\text{C}, T_A = 25 \text{ }^\circ\text{C}, R_{JC} = 0.04 \text{ }^\circ\text{C/W}, R_{CS} = 0.05 \text{ }^\circ\text{C/W}$$

$$\text{From Problem 4-3, } P_T = 241.25 \text{ W}$$

$$P_T(R_{JC} + R_{CS} + R_{SA}) = T_J - T_A = 150 - 25 = 125$$

$$R_{SA} = 125/241.25 - 0.04 - 0.05 = 0.0681 \text{ }^\circ\text{C/W}$$

Problem 4-5

$$B_{BE(\text{sat})} = 3 \text{ V}, I_B = 8 \text{ A}, T = 1/f_s = 100 \text{ } \mu\text{s}, k = 0.5, kT = 50 \text{ } \mu\text{s}, t_d = 0.5 \text{ } \mu\text{s}, t_r = 1 \text{ } \mu\text{s}, t_n = 50 - 1.5 = 48.5 \text{ } \mu\text{s}, t_s = 5 \text{ } \mu\text{s}, t_f = 3 \text{ } \mu\text{s}, t_{on} = t_d + t_r = 1.5 \text{ } \mu\text{s}, t_{off} = t_s + t_f = 5 + 3 = 8 \text{ } \mu\text{s}$$

(a) During the period, $0 \leq t \leq (t_{on} + t_n)$:

$$i_b(t) = I_{BS}$$

$$v_{BE}(t) = V_{BE(sat)}$$

The instantaneous power due to the base current is

$$P_b(t) = i_b v_{BE} = I_{BS} V_{BE(sat)} = 8 \times 3 = 24 \text{ W}$$

During the period, $0 \leq t \leq t_o = (T - t_{on} - t_n)$: $P_b(t) = 0$

From Eq. (4-35), the average power loss is

$$\begin{aligned} P_B &= I_{BS} V_{BE(sat)} (t_{on} + t_n + t_s) f_s \\ &= 8 \times 3 \times (1.5 + 48.5 + 5) \times 10^{-6} \times 10 \times 10^3 = 13.2 \text{ W} \end{aligned}$$

Problem 4-6

$V_{CC} = 200 \text{ V}$, $V_{BE(sat)} = 2.3 \text{ V}$, $I_B = 8 \text{ A}$, $V_{CE(sat)} = 1.4 \text{ V}$, $I_{CS} = 100 \text{ A}$, $t_d = 0.1 \mu\text{s}$, $t_r = 0.45 \mu\text{s}$, $t_s = 3.2 \mu\text{s}$, $t_f = 1.1 \mu\text{s}$, $f_s = 10 \text{ kHz}$, $k = 0.5$, $T = 1/f_s = 100 \mu\text{s}$. $kT = t_d + t_r + t_n = 50 \mu\text{s}$ and $t_n = 50 - 0.45 - 0.1 = 49.45 \mu\text{s}$, $(1-k)T = t_s + t_f + t_o = 50 \mu\text{s}$ and $t_o = 50 - 3.2 - 1.1 = 45.7 \mu\text{s}$.

(a) From Eq. (4-21),

$$P_c(t) = 3 \times 10^{-3} \times 200 = 0.6 \text{ W}$$

$$P_d = 3 \times 10^{-3} \times 200 \times 0.1 \times 10^{-6} \times 10 \times 10^3 = 0.6 \text{ mW}$$

During rise time, $0 \leq t \leq t_r$:

$$\text{From Eq. (4-23), } t_m = 0.45 \times 200 / [2(200 - 1.4)] = 0.2266 \mu\text{s}$$

$$\text{From Eq. (4-24), } P_p = 200^2 \times 100 / [4(200 - 1.4)] = 5035.25 \text{ W}$$

From Eq. (4-25),

$$P_r = 10 \times 10^3 \times 100 \times 0.45 \times 10^{-6} [220/2 + (1.4 - 200)/3] = 15.21 \text{ W}$$

$$P_{on} = P_d + P_r = 0.0006 + 15.21 \text{ W} = 15.21 \text{ W}$$

(b) Conduction Period, $0 \leq t \leq t_n$:

$$P_c(t) = 1.4 \times 100 = 280 \text{ W}$$

$$\text{From Eq. (4-27), } P_n = 1.4 \times 100 \times 49.45 \times 10^{-6} \times 10 \times 10^3 = 69.23 \text{ W}$$

(c) Storage Period, $0 \leq t \leq t_s$:

$$P_c(t) = 1.4 \times 100 = 140 \text{ W}$$

From Eq. (4-28), $P_s = 1.4 \times 100 \times 3.2 \times 10^{-6} \times 10 \times 10^3 = 4.48 \text{ W}$

Fall time, $0 \leq t \leq t_f$:

From Eq. (4-30), $P_p = 200 \times 100/4 = 5000 \text{ W}$

From Eq. (4-31), $P_f = 200 \times 100 \times 1.1 \times 10^{-6} \times 10 \times 10^3/6 = 36.67 \text{ W}$

$P_{\text{off}} = P_s + P_f = 4.48 + 36.67 = 41.15 \text{ W}$

(d) Off-period, $0 \leq t \leq t_o$:

$P_c(t) = 3 \times 10^{-3} \times 200 = 0.6 \text{ W}$

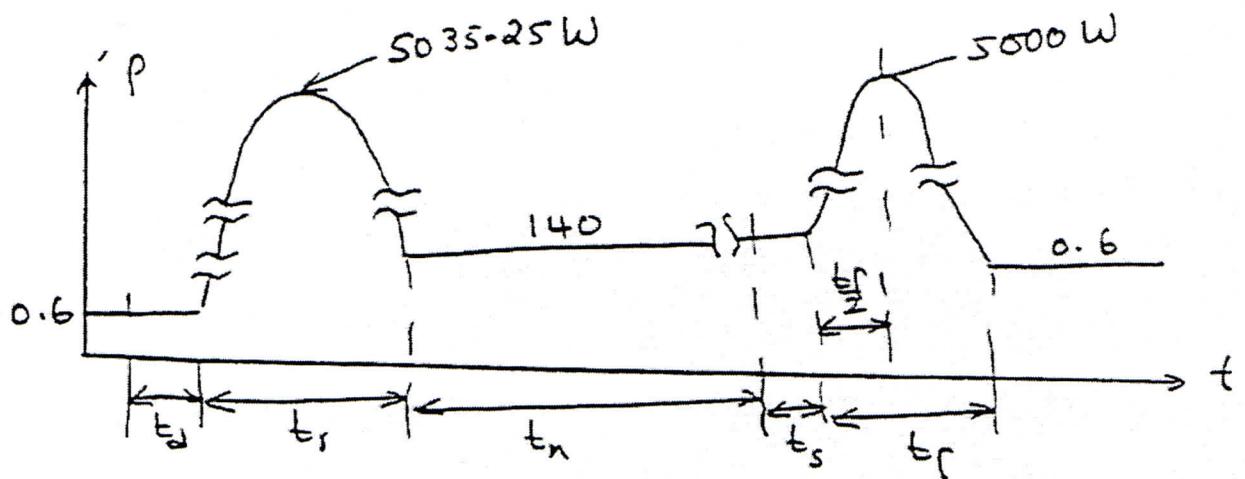
From Eq. (4-33),

$P_o = 3 \times 10^{-3} \times 200 \times 45.7 \times 10^{-6} \times 10 \times 10^3 = 0.274 \text{ W}$

(e) The total power loss in the transistor due to collector current is

$P_T = P_{\text{on}} + P_n + P_{\text{off}} + P_o = 15.21 + 69.23 + 41.15 + 0.274 = 125.87 \text{ W}$

(f)



Problem 4-7

$V_{DD} = 40 \text{ V}$, $I_D = 35 \text{ A}$, $I_{DSS} = 250 \mu\text{A}$, $R_{DS} = 28 \text{ m}\Omega$, $V_{GS} = 10 \text{ V}$, $t_{d(\text{on})} = 25 \text{ ns}$, $t_r = 60 \text{ ns}$, $t_{d(\text{off})} = 70 \text{ ns}$, $t_f = 25 \text{ ns}$, $f_s = 20 \text{ kHz}$, $k = 0.6$, $T = 1/f_s = 50 \mu\text{s}$. $kT = t_{d(\text{on})} + t_r + t_n = 50000 \text{ ns}$ and $t_n = 50000 - 25 - 60 = 29915 \text{ ns}$, $(1-k)T = t_f + t_{d(\text{off})} + t_o = 20000 \text{ ns}$ and $t_o = 20000 - 70 - 25 = 19905 \text{ ns}$.

(a) During delay time, $0 \leq t \leq t_{d(\text{on})}$:

$$i_D(t) = I_{DSS}$$

$$v_{DS}(t) = V_{DD}$$

The instantaneous power due to the collector current is

$$P_D(t) = i_D v_{DS} = I_{DSS} V_{DD} = 250 \times 10^{-3} \times 40 = 0.01 \text{ W}$$

The average power loss during the delay time is

$$\begin{aligned} \text{From Eq. (4-21), } P_d &= I_{DSS} V_{DD} t_{d(\text{on})} f_s \\ &= 250 \times 10^{-3} \times 40 \times 25 \times 10^{-9} \times 20 \times 10^3 = 5 \text{ mW} \end{aligned}$$

During rise time, $0 \leq t \leq t_r$:

$$i_D(t) = \frac{I_{DS}}{t_r} t$$

$$v_{DS}(t) = V_{DD} + (R_{DS} I_{DS} - V_{DD}) \frac{t}{t_r}$$

From Eq. (4-22)

$$P_D(t) = i_D v_{DS} = \frac{I_{DS}}{t_r} t \left[V_{DD} + (R_{DS} I_{DS} - V_{DD}) \frac{t}{t_r} \right]$$

From Eq. (4-23) the power $P_D(t)$ will be maximum when $t = t_m$, where

$$t_m = \frac{t_r V_{DD}}{2(V_{DD} - R_{DS} I_{DS})} = \frac{60 \times 10^{-9} \times 40}{2 \times (40 - 25 \times 10^{-3} \times 35)} = 30.67 \text{ ns}$$

and Eq. (4-24) yields the peak power

$$P_p = \frac{V_{DD}^2 I_{DS}}{4(V_{CC} - V_{CE(\text{sat})})} = \frac{40^2 \times 35}{4(40 - 25 \times 10^{-3} \times 35)} = 357.83 \text{ W}$$

From Eq. (4-25).

$$P_r = f_s I_{DS} t_r \left[\frac{V_{DD}}{2} + \frac{R_{DS} I_{DS} - V_{CC}}{3} \right]$$

$$= 20 \times 10^3 \times 35 \times 60 \times 10^{-9} [40/2 + (25 \times 10^{-3} \times 35 - 40)/3] = 1.3877 \text{ W}$$

The total power loss during the turn-on is

$$P_{\text{on}} = P_d + P_r = 0.005 + 1.3877 = 1.39275 \text{ W}$$

(b) Conduction Period, $0 \leq t \leq t_n$:

$$i_D(t) = I_{DS}$$

$$v_{DS}(t) = R_{DS} I_{DS}$$

$$P_D(t) = i_D v_{DS} = R_{DS} I_{DS} I_{DS} = 25 \times 10^{-3} \times 35^2 = 30.625 \text{ W}$$

From Eq. (4-27), $P_n = R_{DS} I_{DS} I_{DS} t_n f_s$

$$= 25 \times 10^{-3} \times 35^2 \times 29915 \times 10^{-9} \times 20 \times 10^3 = 18.32 \text{ W}$$

(c) Storage Period, $0 \leq t \leq t_{d(\text{off})}$:

$$i_D(t) = I_{DS}$$

$$v_{DS}(t) = R_{DS} I_{DS}$$

$$P_c(t) = i_D v_{DS} = R_{DS} I_{DS} I_{DS} = 25 \times 10^{-3} \times 35^2 = 30.625 \text{ W}$$

$P_{D(\text{off})} = R_{DS} I_{DS} I_{DS} t_{d(\text{off})} f_s$

$$= 25 \times 10^{-3} \times 35^2 \times 70 \times 10^{-9} \times 20 \times 10^3 = 42.87 \text{ mW}$$

Fall time, $0 \leq t \leq t_f$:

$$i_D(t) = I_{DS} \left(1 - \frac{t}{t_f} \right)$$

$$v_{DS}(t) = \frac{V_{DD}}{t_f} t$$

$$P_D(t) = V_{DD} I_{DS} \left[\left(1 - \frac{t}{t_f} \right) \frac{t}{t_f} \right]$$

This power loss during fall time will be maximum when $t = t_f/2 = 12.5 \text{ ns}$.

From Eq. (4-30), the peak power,

$$P_D = V_{DD} I_{DS} / 4 = 40 \times 35 / 4 = 350 \text{ W}$$

From Eq. (4-31), $P_f = V_{DD} I_{DS} t_f f_s / 6$

$$= 40 \times 35 \times 25 \times 10^{-9} \times 20 \times 10^3 / 6 = 0.117 \text{ W}$$

The power loss during turn-off is

$$P_{\text{off}} = P_{D(\text{off})} + P_f = 0.04287 + 0.117 = 0.15987 \text{ W}$$

(d) Off-period, $0 \leq t \leq t_o$:

$$i_D(t) = I_{DSS}$$

$$v_{DS}(t) = V_{DD}$$

$$P_D(t) = i_D v_{DS} = I_{DSS} V_{DD} = 250 \times 10^{-6} \times 40 = 10 \text{ mW}$$

$$P_o = I_{DSS} V_{DD} t_o f_s$$

$$= 250 \times 10^{-6} \times 40 \times 19905 \times 10^{-9} \times 20 \times 10^3 = 3.981 \text{ mW}$$

(e) The total power loss in the transistor due to collector current is

$$P_T = P_{on} + P_n + P_{off} + P_o$$

$$= 1.3927 + 18.32 + 0.04287 + 0.01 = 20.466 \text{ W}$$

Problem 4-8

From Problem 4-7, $P_T = 20.466 \text{ W}$

$$R_{JC} = 1 \text{ }^\circ\text{K/W}, R_{CS} = 1 \text{ }^\circ\text{K/W}, T_J = 150 \text{ }^\circ\text{C}, T_A = 30 \text{ }^\circ\text{C}$$

$$T_J = 150 \text{ }^\circ\text{C} + 273 = 423 \text{ }^\circ\text{K}$$

$$T_A = 30 \text{ }^\circ\text{C} + 273 = 303 \text{ }^\circ\text{K}$$

$$P_T(R_{JC} + R_{CS} + R_{SA}) = T_J - T_A = 423 - 303 = 120$$

$$R_{SA} = 120/20.466 - 1 - 1 = 3.863 \text{ }^\circ\text{K/W}$$

Problem 4-9

$$I_T = 200 \text{ A}, V_{CE1} = 1.5 \text{ V}, V_{CE2} = 1.1 \text{ V}$$

$$(a) R_{e1} = 10 \text{ m}\Omega, R_{e2} = 20 \text{ m}\Omega$$

$$I_{E1} + I_{E2} = I_T$$

$$V_{CE1} + I_{E1} R_{e1} = V_{CE2} + I_{E2} R_{e2}$$

$$\text{or } I_{E1} = (V_{CE2} - V_{CE1} + I_T R_{e2}) / (R_{e1} + R_{e2})$$

$$= (1.1 - 1.5 + 200 \times 20 \times 10^{-3}) / (0.01 + 0.02) = 120 \text{ A or } 60 \%$$

$$I_{E2} = 200 - 120 = 80 \text{ A or } 40 \%. \quad \Delta I = 60 - 40 = 20 \%$$

$$(b) R_{e1} = R_{e2} = 20 \text{ m}\Omega$$

$$I_{E1} = (1.1 - 1.5 + 200 \times 20 \times 10^{-3}) / (0.01 + 0.02) = 90 \text{ A or } 45 \%$$

$$I_{E2} = 200 - 90 = 110 \text{ A or } 55 \%. \quad \Delta I = 55 - 45 = 10 \%$$

Problem 4-10

$$I_L = 100 \text{ A}, V_s = 400 \text{ V}, f_s = 20 \text{ kHz}, t_r = 1 \mu\text{s}, \text{ and } t_f = 3 \mu\text{s}.$$

(a) From Eq. (4-44), $L_s = 440 \times 1/100 = 4 \mu\text{H}$

(b) From Eq. (4-46), $C_s = 100 \times 3/400 = 0.75 \mu\text{F}$

(c) From Eq. (4-47), $R_s = 2 \sqrt{4/0.75} = 4.62 \Omega$

(d) From Eq. (4-48), $R_s = 10^3 / (3 \times 20 \times 0.75) = 22.2 \Omega$

(e) $V_s/R_s = 0.05 \times I_L$ or $400/R_s = 0.05 \times 100$ or $R_s = 80 \Omega$

(f) From Eq. (4-49), the snubber loss is

$$P_s = 0.5 C_s V_s^2 f_s = 0.5 \times 0.75 \times 10^{-6} \times 400^2 \times 20 \times 10^3 = 1200 \text{ W}$$

Problem 4-11

$$I_L = 40 \text{ A}, V_s = 30 \text{ V}, f_s = 50 \text{ kHz}, t_r = 60 \text{ ns}, \text{ and } t_f = 25 \text{ ns}$$

(a) From Eq. (4-44), $L_s = 30 \times 60 \times 10^{-9} / 40 = 0.045 \mu\text{H}$

(b) From Eq. (4-46), $C_s = 40 \times 25 \times 10^{-9} / 30 = 0.0333 \mu\text{F}$

(c) From Eq. (4-47), $R_s = 2 \sqrt{45/33.33} = 2.324 \Omega$

(d) From Eq. (4-48), $R_s = 10^6 / (3 \times 50 \times 33.33) = 200 \Omega$

(e) $V_s/R_s = 0.05 \times I_L$ or $30/R_s = 0.05 \times 40$ or $R_s = 15 \Omega$

(f) From Eq. (4-49), the snubber loss is

$$P_s = 0.5 C_s V_s^2 f_s$$

$$= 0.5 \times 33.33 \times 10^{-9} \times 30^2 \times 50 \times 10^3 = 0.75 \text{ W}$$

CHAPTER 5
DC-DC CONVERTERS

Problem 5-1

$V_s = 220 \text{ V}$, $k = 0.8$, $R = 20 \ \Omega$ and $v_{ch} = 1.5 \text{ V}$.

(a) From Eq. (5-1), $V_a = 0.8 \times (220 - 1.5) = 174.8 \text{ V}$

(b) From Eq. (5-2), $V_o = \sqrt{0.8 \times 220} = \text{V}$

(c) From Eq. (5-5), $P_o = 0.8 \times (220 - 1.5)^2 / 20 = 3819.4 \text{ W}$

From Eq. (5-6), $P_i = 0.8 \times 220 \times (220 - 1.5) / 20 = 3845.6 \text{ W}$

The chopper efficiency is $P_o / P_i = 3819.4 / 3845.6 = 99.32 \%$

(d) From Eq. (5-4), $R_i = 20 / 0.8 = 12.5 \ \Omega$

(e) From Eq. (5-8), the output voltage is

$$\begin{aligned} v_o(t) &= \frac{220}{\pi} \left[\sin(2\pi \times 0.8) \cos(2\pi \times 10000t) + 0.691 \times \sin(2\pi \times 10000t) \right] \\ &= 82.32 \times \sin(62832t + \phi) \end{aligned}$$

where $\phi = \tan^{-1} [\sin(0.8 \times 2\pi) / 0.691] = 54^\circ$.

The rms value is $V_1 = 82.32 / \sqrt{2} = 58.2 \text{ V}$

Note: The efficiency calculation, which includes the conduction loss of the chopper, does not take into account the switching loss due to turn-on and turn-off of the converter.

Problem 5-2

$V_s = 220 \text{ V}$, $R = 10 \ \Omega$, $L = 15.5 \text{ mH}$, $E = 20 \text{ V}$, $k = 0.5$ and $f = 5000 \text{ Hz}$

From Eq. (5-15), $I_2 = 0.9375 I_1 + 1.2496$

From Eq. (5-16), $I_1 = 0.9375 I_2 - 1.2496$

(a) Solving these two equations, $I_1 = 8.6453 \text{ A}$

(b) $I_2 = 9.3547 \text{ A}$

(c) $\Delta I = I_2 - I_1 = 9.35475 - 8.6453 = 0.7094 \text{ A}$

From Eq. (5-21), $\Delta I_{\max} = 0.7094 \text{ A}$

and Eq. (5-22) gives the approximately value, $\Delta I_{\max} = 0.7097 \text{ A}$

(d) The average load current is approximately,

$$I_a = (I_2 + I_1)/2 = (9.35475 + 8.6453)/2 = 9 \text{ A}$$

(e) From Eq. (5-24),

$$I_o = \left[I_1^2 + \frac{(I_2 - I_1)^2}{3} + I_1(I_2 - I_1) \right]^{1/2} = 9.002 \text{ A}$$

(f) $I_s = k I_a = 0.8 \times 9 = 7.2 \text{ A}$

and the input resistance is $R_i = V_s/I_s = 220/7.2 = 30.56 \Omega$

(g) From Eq. (5-25), $I_R = \sqrt{k} I_o = \sqrt{0.8} \times 22.1 = 15.63 \text{ A}$

Problem 5-3

$$V_s = 220 \text{ V}, R = 0.2 \Omega, E = 10 \text{ V}, f = 200 \text{ Hz}, T = 1/f = 0.005 \text{ s}$$

$$\Delta i = 200 \times 0.5 = 10 \text{ A.}$$

$$V_a = k V_s = R I_a$$

The voltage across the inductor is given by

$$L \frac{di}{dt} = V_s - R I_a = V_s - k V_s = (1-k) V_s$$

For a linear rise of current, $dt = t_1 = kT$ and $di = \Delta i$

$$\Delta i = \frac{(1-k) V_s}{L} k T$$

For worst case ripple condition: $\frac{d(\Delta i)}{dk} = 0$

and this gives, $k = 0.5$

$$\Delta i L = 10 \times L = 220 (1 - 0.5) 0.5 \times 0.005 \text{ or } L = 27.5 \text{ mH}$$

Problem 5-4

$$V_s = 110 \text{ V}, E = 220 \text{ V}, P_o = 30 \text{ kW} = 30000 \text{ W}$$

(c) Since the input power must be the same as the output power,

$$V_s I_s = P_o \text{ or } 110 \times I_s = 30000 \text{ or } I_s = \text{A}$$

(a) The battery current, $I_b = P_o/E = 30000/220 = 136.36 \text{ A}$

$$I_b = (1 - k) I_s \text{ or } k = 136.36/272.73 - 1 = 0.5$$

$$(b) R_{ch} = (1 - k) E/I_s = (1 - 0.5) \times 220/272.73 = 0.4033 \Omega$$

Problem 5-5

$$V_s = 110 \text{ V}, L = 7.5 \text{ mH}, E = 220 \text{ V}$$

$$\text{From Eq. (5-28), } i_1(t) = (110 \times 10^3/7.5) t + I_1$$

From Eq. (5-29),

$$i_2(t) = [(110 - 220) \times 10^3/7.5] t + I_2 = -(110 \times 10^3/7.5) t + I_2$$

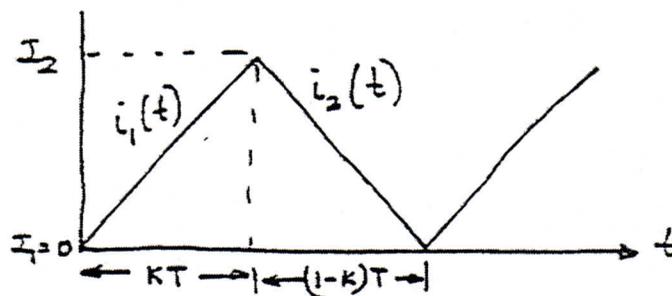
$$\text{where } I_2 = i_1(t=kT) = (110 \times 10^3/7.5) kT + I_1$$

$$I_1 = i_2[t=(1-k)T] = -(110 \times 10^3/7.5) (1-k)T + I_2$$

Solving for I_1 and I_2 yields $I_1 = 0$, $I_2 = (110 \times 10^3/7.5) kT$

$$i_1(t) = (110 \times 10^3/7.5) t, \text{ for } 0 \leq t \leq kT$$

$$i_2(t) = -(110 \times 10^3/7.5)t + (110 \times 10^3/7.5)(1-k)T, \text{ for } 0 \leq t \leq (1 - k)T.$$



Problem 5-6

$V_s = 600 \text{ V}$, $R = 0.25 \ \Omega$, $L = 20 \text{ mH}$, $E = 150 \text{ V}$, $k = 0.1$ to 0.9 and $f = 250$
Hz

For $k=0.1$, the load current is discontinuous

From Eq. (5-15), $I_2 = 8.977$

From Eq. (5-16), $I_1 = 0$, $\Delta I = 8.977 \text{ A}$ and $I_a = 4.4885 \text{ A}$

For $k=0.2$, the load current is discontinuous

$I_2 = 17.9103 \text{ A}$, $I_1 = 0 \text{ A}$, $\Delta I = 17.9103 \text{ A}$ and $I_a = 8.955 \text{ A}$

For $k = 0.3$

$I_2 = 0.9851 I_1 + 26.7985$, $I_1 = 0.9656 I_2 - 20.6367$

$I_2 = 132.64 \text{ A}$, $I_1 = 107.44 \text{ A}$, $\Delta I = 25.2 \text{ A}$ and $I_a = 120.04 \text{ A}$

For $k = 0.4$

$I_2 = 0.9802 I_1 + 35.64$, $I_1 = 0.97044 I_2 - 17.733$

$I_2 = 374.42 \text{ A}$, $I_1 = 345.62 \text{ A}$, $\Delta I = 28.8 \text{ A}$ and $I_a = 360.02 \text{ A}$

For $k = 0.5$

$I_2 = 0.9753 I_1 + 44.44$, $I_1 = 0.97045 I_2 - 14.814$

$I_2 = 615 \text{ A}$, $I_1 = 585 \text{ A}$, $\Delta I = 30 \text{ A}$ and $I_a = 600 \text{ A}$

For $k = 0.6$

$I_2 = 0.97044 I_1 + 53.2$, $I_1 = 0.9802 I_2 - 11.881$

$I_2 = 854.38 \text{ A}$, $I_1 = 825.58 \text{ A}$, $\Delta I = 28.8 \text{ A}$ and $I_a = 840 \text{ A}$

For $k = 0.7$

$I_2 = 0.9656 I_1 + 61.91$, $I_1 = 0.9851 I_2 - 8.933$

$I_2 = 1092.6 \text{ A}$, $I_1 = 1067.4 \text{ A}$, $\Delta I = 25.2 \text{ A}$ and $I_a = 1080 \text{ A}$

For $k = 0.8$

$I_2 = 0.9608 I_1 + 70.58$, $I_1 = 0.99 I_2 - 5.97$

$I_2 = 1329.6 \text{ A}$, $I_1 = 1310.4 \text{ A}$, $\Delta I = 19.2 \text{ A}$ and $I_a = 1320 \text{ A}$

For $k = 0.9$

$$I_2 = 0.956 I_1 + 79.2, I_1 = 0.995 I_2 - 2.99$$

$$I_2 = 1565.4 \text{ A}, I_1 = 1554.6 \text{ A}, \Delta I = 10.8 \text{ A and } I_a = 1560 \text{ A}$$

Problem 5-7

$V_s = 600 \text{ V}, R = 0.25 \Omega, L = 20 \text{ mH}, E = 150 \text{ V}, k = 0.1 \text{ to } 0.9$ and $f = 250 \text{ Hz}$

The maximum ripple occurs at $k = 0.5$.

From Eq. (5-21), $\Delta I_{\max} = (600/0.25) \tanh [0.25/(4 \times 250 \times 0.02)] = 29.9985 \text{ A}$.

From Eq. (5-22), $\Delta I_{\max} = [600/(4 \times 250 \times 0.02)] = 30 \text{ A}$

Problem 5-8

$V_s = 10 \text{ V}, f = 1 \text{ kHz}, R = 10 \Omega, L = 6.5 \text{ mH}, E = 5 \text{ V}$ and $k = 0.5$.

$$V_s := 10 \quad R := 10 \quad L := 6.5 \cdot 10^{-3} \quad f := 1000$$

$$E := 5 \quad k := 0.5 \quad T := \frac{1}{f} \quad z := \frac{T \cdot R}{L} \quad z = 1.54$$

From Eq. (5-35), we get

$$I_1 := \frac{V_s \cdot k \cdot z}{R} \cdot \frac{e^{-(1-k) \cdot z}}{1 - e^{-(1-k) \cdot z}} + \frac{V_s - E}{R} \quad I_1 = 1.16 \text{ A}$$

From Eq. (5-36), we get

$$I_2 := \frac{V_s \cdot k \cdot z}{R} \cdot \frac{1}{1 - e^{-(1-k) \cdot z}} + \frac{V_s - E}{R} \quad I_2 = 1.93 \text{ A}$$

$$\Delta I := I_2 - I_1 \quad \Delta I = 0.77 \text{ A}$$

Problem 5-9

$V_s = 15 \text{ V}$, $\Delta V_c = 10 \text{ mV}$, $\Delta I = 0.5 \text{ A}$, $f = 20 \text{ kHz}$, $V_a = 5 \text{ V}$ and $I_a = 0.5 \text{ A}$

(a) From Eq. (5-48), $V_a = k V_s$ and $k = V_a/V_s = 5/15 = 0.3333$

(b) From Eq. (5-52), $L = 5 (15 - 5)/(0.5 \times 20000 \times 15) = 333.3 \mu\text{H}$

(c) From Eq. (5-53), $C = 0.5/(8 \times 10 \times 10^{-3} \times 20000) = 312.5 \mu\text{F}$

$$(d) \quad R := \frac{V_a}{I_a} \quad R = 10$$

$$\text{From Eq. (5-56)} \quad L_c(k) := \frac{(1-k) \cdot R}{2 \cdot f} \quad L_c(0.333) \cdot 10^6 = 166.75 \mu\text{H}$$

$$\text{From Eq. (5-89)} \quad C_c(k) := \frac{1-k}{16 \cdot L_c(0.333) \cdot f^2} \quad C_c(0.333) \cdot 10^6 = 0.63 \mu\text{F}$$

Problem 5-10

$V_s = 6 \text{ V}$, $V_a = 15 \text{ V}$, $I_a = 0.5 \text{ A}$, $f = 20 \text{ kHz}$, $L = 250 \mu\text{H}$, and $C = 440 \mu\text{F}$.

(a) From Eq. (5-62) $15 = 6/(1 - k)$ or $k = 3/5 = 0.6 = 60 \%$

(b) From Eq. (5-67), $\Delta I = 6 \times (15 - 6)/(20000 \times 250 \times 10^{-6} \times 15)$
 $= 0.72 \text{ A}$

(c) From Eq. (5-65), $I_s = 0.5/(1 - 0.6) = 1.25 \text{ A}$

Peak inductor current, $I_2 = I_s + \Delta I/2 = 1.25 + 0.72/2 = 1.61 \text{ A}$

(d) From Eq. (5-71), $\Delta V_c = 0.5 \times 0.6/(20000 \times 440 \times 10^{-6}) = 34.1 \text{ mV}$

$$(e) \quad R := \frac{V_a}{I_a} \quad R = 30$$

$$\text{From Eq. (5-72)} \quad L_c(k) := \frac{k \cdot (1 - k) \cdot R}{2 \cdot f} \quad L_c(0.6) \cdot 10^6 = 180 \quad \mu\text{H}$$

$$\text{From Eq. (5-73)} \quad C_c(k) := \frac{k}{2 \cdot f \cdot R} \quad C_c(0.6) \cdot 10^6 = 0.5 \quad \mu\text{F}$$

Problem 5-11

$V_s = 12 \text{ V}$, $k = 0.6$, $I_a = 1.5 \text{ A}$, $f = 25 \text{ kHz}$, $L = 250 \mu\text{H}$, and $C = 220 \mu\text{F}$

(a) From Eq. (5-78), $V_a = -12 \times 0.6 / (1 - 0.6) = -18 \text{ V}$

(b) From Eq. (5-87), the peak-to-peak output ripple voltage is

$$\Delta V_c = 1.5 \times 0.6 / (25000 \times 220 \times 10^{-6}) = 163.64 \text{ mV}$$

(c) From Eq. (5-84), the peak-to-peak inductor ripple voltage is

$$\Delta I = 12 \times 0.6 / (25000 \times 250 \times 10^{-6}) = 1.152 \text{ A}$$

(d) From Eq. (5-81), $I_s = 1.5 \times 0.6 / (1 - 0.6) = 2.25 \text{ A}$

Since I_s is the average of duration kT , the peak to peak current of transistor,

$$I_p = I_s/k + \Delta I/2 = 2.25/0.6 + 1.152/2 = 4.326 \text{ A}$$

$$(e) \quad R := \frac{-V_a}{I_a} \quad R = \blacksquare$$

$$\text{From Eq. (5-88)} \quad L_c(k) := \frac{(1 - k) \cdot R}{2 \cdot f} \quad L_c(0.6) \cdot 10^6 = \blacksquare \quad \mu\text{H}$$

$$\text{From Eq. (5-89)} \quad C_c(k) := \frac{k}{2 \cdot f \cdot R} \quad C_c(0.6) \cdot 10^6 = \blacksquare \quad \mu\text{F}$$

Problem 5-12

$V_s = 15 \text{ V}$, $k = 0.4$, $I_a = 1.25 \text{ A}$, $f = 25 \text{ kHz}$, $L_1 = 250 \mu\text{H}$, $C_1 = 400 \mu\text{F}$, $L_2 = 350 \mu\text{H}$ and $C_2 = 220 \mu\text{F}$

(a) From Eq. (5-100), $V_a = -0.4 \times 15 / (1 - 0.4) = -10 \text{ V}$

(b) From Eq. (5-103), $I_s = 1.25 \times 0.4 / (1 - 0.4) = 0.83 \text{ A}$

(c) From Eq. (5-106), $\Delta I_1 = 15 \times 0.4 / (25000 \times 250 \times 10^{-6}) = 0.96 \text{ A}$

(d) From Eq. (5-112), $\Delta V_{c1} = 0.83 (1 - 0.4) / (25000 \times 400 \times 10^{-6}) = 50 \text{ mV}$

(e) From Eq. (5-109), $\Delta I_2 = 0.4 \times 15 / (25000 \times 350 \times 10^{-6}) = 0.69 \text{ A}$

(f) From Eq. (5-113), $\Delta V_{c2} = 0.69 / (8 \times 25000 \times 220 \times 10^{-6}) = 15.58 \text{ mV}$

(g) From Eq. (5-120), $\Delta I_{L2} = 1.25 / (1.0 - 2 \times 0.4) = 6.25 \text{ A}$

$I_p = I_s + I_1/2 + I_{L2} + \Delta I_2/2 = 0.83 + 0.96/2 + 6.25 + 0.69/2 = 7.91 \text{ A}$

Problem 5-13

$V_s = 15 \text{ V}$, $k = 0.4$, $I_a = 1.25 \text{ A}$, $f = 25 \text{ kHz}$, $L_1 = 250 \mu\text{H}$, $C_1 = 400 \mu\text{F}$, $L_2 = 350 \mu\text{H}$ and $C_2 = 220 \mu\text{F}$

$V_s := 15$ $k := 0.4$ $I_a := 1.25$ $f := 25 \cdot 10^3$

From Eq. (5-115) $L_{c1}(k) := \frac{(1-k) \cdot R^2}{2 \cdot k \cdot f}$ $L_{c1}(0.4) \cdot 1000 = 4.32 \text{ mH}$

From Eq. (5-116) $L_{c2}(k) := \frac{(1-k) \cdot R}{2 \cdot f}$ $L_{c2}(0.4) \cdot 1000 = 0.14 \text{ mH}$

From Eq. (5-117) $C_{c1}(k) := \frac{k}{2 \cdot f \cdot R}$ $C_{c1}(0.5) \cdot 10^6 = 0.83 \mu\text{F}$

From Eq. (5-118) $C_{c2}(k) := \frac{1}{8 \cdot f \cdot R}$ $C_{c2}(0.5) \cdot 10^6 = 0.42 \mu\text{F}$

Problem 5-14

$V_s = 110 \text{ V}$, $V_a = 80 \text{ V}$, $I_a = 20 \text{ A}$

$$\Delta V_C = 0.05 \times V_a = 0.05 \times 80 = 4 \text{ V}$$

$$R = V_a/I_a = 80/20 = 4 \ \Omega$$

$$\text{From Eq. (5-48), } k = V_a/V_s = 80/110 = 0.7273$$

$$\text{From Eq. (5-49) } I_s = k I_a = 0.7273 \times 20 = 14.55 \text{ A}$$

$$\Delta I_L = 0.025 \times I_a = 0.025 \times 20 = 0.5 \text{ A}$$

$$\Delta I = 0.1 \times I_a = 0.1 \times 20 = 2 \text{ A}$$

(a) From Eq. (5-51), we get the value of L_e

$$L_e = \frac{V_a(V_s - V_a)}{\Delta I f V_s} = \frac{80 \times (110 - 80)}{2 \times 10 \text{ kHz} \times 110} = 1.091 \text{ mH}$$

From Eq. (5-128), we get the value of C_e

$$C_e = \frac{\Delta I}{V_C 8f} = \frac{2}{4 \times 8 \times 10 \text{ kHz}} = 6.25 \ \mu\text{F}$$

Assuming a linear rise of load current i_L during the time from $t = 0$ to $t_1 = kT$, Eq. (5-129) gives the approximate value of L as

$$L_e = \frac{kT\Delta V_C}{\Delta I_L} = \frac{k\Delta V_C}{\Delta I_L f} = \frac{0.7273 \times 4}{0.5 \times 10 \text{ kHz}} = 0.582 \text{ mH}$$

Problem 5-15

PSpice simulation

Problem 5-16

$k = 0.4$, $R = 150 \ \Omega$, $r_L = 1 \ \Omega$ and $r_C = 0.2 \ \Omega$.

$$k := 0.5 \quad R := 150 \quad r_L := 1 \quad r_c := 0.2$$

(a) Buck

$$G(k) := \frac{k \cdot R}{R + r_L} \qquad G(0.5) = 0.5$$

(b) Boost

$$G(k) := \frac{1}{1-k} \cdot \left[\frac{(1-k)^2 \cdot R}{(1-k)^2 \cdot R + r_L + k \cdot (1-k) \cdot \frac{r_c \cdot R}{r_c + R}} \right] \qquad G(0.5) = 1.95$$

(c) Buck – Boost

$$G(k) := \frac{-k}{1-k} \cdot \left[\frac{(1-k)^2 \cdot R}{(1-k)^2 \cdot R + r_L + k \cdot (1-k) \cdot \frac{r_c \cdot R}{r_c + R}} \right] \qquad G(0.5) = -0.97$$