

Chapter 1

1-1

$$1 \text{ yr} = 365 \frac{\text{days}}{\text{yr}} \times 24 \frac{\text{hrs}}{\text{day}} = 8760 \text{ hrs}$$

Average
Wasted
Power

$$P_{\text{avg}} = \frac{122 \times 10^9 \text{ kWh/yr}}{8760 \text{ hr/yr}} = 13.92 \times 10^3 \text{ MW}$$

(a)

$\therefore \sim 13$ 1,100-MW generating plants
running continuously provide this power.

$$\begin{aligned} \text{(b) Annual Savings} &= 0.12 \frac{\$}{\text{kWh}} \times 122 \times 10^9 \frac{\text{kWh}}{\text{yr}} \\ &= 14.64 \text{ Billion } \$/\text{yr} \end{aligned}$$

1-2

For the ease of solving this problem, let us assume that the system operates for 100 hrs and draws 1 kW while delivering 100% flow rate.

The percentage reduction in the power consumption is the same as the percentage reduction in the energy consumption.

The following Table shows the energy consumption using each of the three methods:

<u>hrs of Operation</u>	<u>Drive</u>	<u>Outlet</u>	<u>Inlet</u>
20 hrs @ 100%	1 x 20 kWh	1 x 20 kWh	1 x 20 kWh
20 hrs @ 80%	0.5 x 20	0.92 x 20	0.81 x 20
30 hrs @ 60%	0.3 x 30	0.87 x 30	0.7 x 30
10 hrs @ 30%	0.1 x 10	0.72 x 10	0.65 x 10
Total Energy Consumption	$E = 40 \text{ kWh}$ Drive	$E = 71.7 \text{ kWh}$ Outlet	$E = 63.7 \text{ kWh}$ Inlet

Using an adjustable speed drive,

$$(a) \% \text{ reduction over outlet damper} = \frac{E_{\text{outlet}} - E_{\text{Drive}}}{E_{\text{outlet}}} = \frac{71.7 - 40}{71.7} \times 100 \approx 44\%$$

$$(b) \% \text{ reduction over inlet vanes} = \frac{E_{\text{inlet}} - E_{\text{Drive}}}{E_{\text{inlet}}} = \frac{63.7 - 40}{63.7} \times 100 \approx 37\%$$

Problem 1-3

$$P_o = \frac{\eta}{1-\eta} P_{loss} \quad (1-2)$$

$$@ \quad \eta = 87\% = 0.87$$

$$P_{o1} = \frac{0.87}{1-0.87} P_{loss} = 6.69 P_{loss}$$

$$@ \quad \eta = 95\% = 0.95$$

$$P_{o2} = \frac{0.95}{1-0.95} P_{loss} = 19.0 P_{loss}$$

$\therefore$ The power densities^(PD) are related to the output power

$$\frac{PD_2}{PD_1} = \frac{19.0}{6.69} = 2.84$$

$\therefore$ The improvement in power density is

$$\frac{PD_2 - PD_1}{PD_1} = \frac{PD_2}{PD_1} - 1 = 1.84$$

or the power density is 184%

Problem 1-4

$$\begin{aligned}\text{Energy saved per year} &= 3.8 \times 10^9 \times 0.16 \times 0.3 \\ &= 182.4 \times 10^6 \text{ MW-hrs}\end{aligned}$$

$$1 \text{ year} = 365 \times 24 = 8760 \text{ hrs}$$

$\therefore$ Power need to supply wasted energy

$$\begin{aligned}P &= \frac{182.4 \times 10^6}{8760} \text{ MW} \\ &= 20822 \text{ MW}\end{aligned}$$

$\therefore$ Approximately 19 generating plants

Each with an output of 1,100 MW are

needed to supply this wasted energy.

Problem 1-5

$$E_{\text{wind}} = 10.8 \times 10^9 \frac{\text{MW-hrs}}{\text{year}}$$

$$\begin{aligned} \text{Number of Wind mills} &= \frac{0.1 \times E_{\text{WIND}} / (\text{no. of hrs per year})}{P_{\text{Wind mill}} \times \text{Capacity factor}} \\ &= \frac{0.1 \times 10.8 \times 10^9 / 8760}{1.5 \times 0.3} \\ &\approx 2.74 \times 10^5 \\ &= 274 \text{ thousand} \end{aligned}$$

Problem 1-6

$$\text{Power rating of power electronics} = 1,500 \text{ kW / windmill}$$

$$\text{from problem 1-5, no. of windmills} = 2.74 \times 10^5$$

$$\begin{aligned} \therefore \text{Total rating of power electronics} \\ \text{interface} &= 1,500 \times 2.74 \times 10^5 \text{ kW} \\ &= 411 \text{ GW} \end{aligned}$$

Problem 1-7

$$E_{\text{Conventional}} = 3.8 \times 10^9 \times 0.19 \text{ MW-hrs/year}$$

$$E_{\text{CFL}} = 0.25 E_{\text{Conventional}}$$

$$\text{Savings in annual energy} = E_{\text{Conventional}} - E_{\text{CFL}}$$

$$= 0.75 E_{\text{Conventional}}$$

$$= 0.75 \times 3.8 \times 10^9 \times 0.19$$

$$= 0.54 \times 10^9 \frac{\text{MW-hrs}}{\text{year}}$$

Problem 1-8

$$\text{Gallons per car per year} = \frac{11,766}{22.1} = 532.4$$

$$\text{Gallons per hybrid per year} = \frac{11,766}{52} = 226.27$$

$$\begin{aligned} \therefore \text{Savings per vehicle per year} &= 532.4 - 226.27 \\ &\approx 306 \text{ gallons of gasoline} \end{aligned}$$

$$1 \text{ barrel of oil} = 20 \text{ gallons of gasoline}$$

$$\begin{aligned} \therefore \text{Savings per vehicle per year} &= \frac{306}{20} \\ &\approx 15.3 \text{ barrels of oil} \end{aligned}$$

Problem 1-9

$$\begin{aligned}\text{Savings per year} &= 150 \times 10^6 \times 306 \\ &= 45.9 \times 10^9 \text{ gallons}\end{aligned}$$

(using Prob 1-8)

$$\begin{aligned}&= 5 \times 45.9 \times 10^9 \text{ lbs of carbon} \\ &= 229 \times 10^9 \text{ lbs of carbon}\end{aligned}$$

Problem 1-10

$$\begin{aligned}\text{Savings of barrels of oil} &= 15.3 \times 150 \times 10^6 \\ &= 2295 \times 10^6 / \text{year}\end{aligned}$$

Problem 1-11

$$\begin{aligned}E_{\text{Fuel cells}} &= 5 \text{ kW} \times 25 \times 10^6 \times 8760 \frac{\text{hrs}}{\text{year}} \frac{\text{kw-hrs}}{\text{year}} \\ &\approx 10^9 \frac{\text{MW-hrs}}{\text{year}}\end{aligned}$$

Problem 1-12

$$\text{Energy needed to cook} = 0.55 \times 2 \text{ kW-hrs}$$

$\therefore$ Energy needed by induction cookers

$$= \frac{0.55 \times 2}{0.8} \text{ kW-hrs}$$

$$= 1.375 \text{ kW-hrs}$$

$$\therefore \text{Energy saved} = (2 - 1.375) \times 20 \times 10^6 \text{ kW-hrs}$$

$$= 12.5 \times 10^6 \text{ kW-hrs}$$

$$= 12.5 \times 10^3 \text{ MW-hrs}$$

Problem 1-13

$$P_{pv} = 800 \times 0.1 = 80 \text{ W/m}^2$$

$$\therefore \text{Area} = \frac{1000 \times 10^6}{80} \text{ m}^2$$

$$= 12.5 \times 10^6 \text{ m}^2$$

$$= 3535 \times 3535 \text{ m}^2$$

Problem 1-14

From Problem 1-13, $\text{Area} = 12.5 \times 10^6 \text{ m}^2$

$$\begin{aligned}\therefore \text{no. of homes} &= \frac{12.5 \times 10^6}{40} \\ &= 312.5 \text{ thousand}\end{aligned}$$

Problem 1-23

$$V_{in} = 12 \text{ V}, \quad V_o = 9 \text{ V}, \quad f_s = 400 \text{ kHz}$$

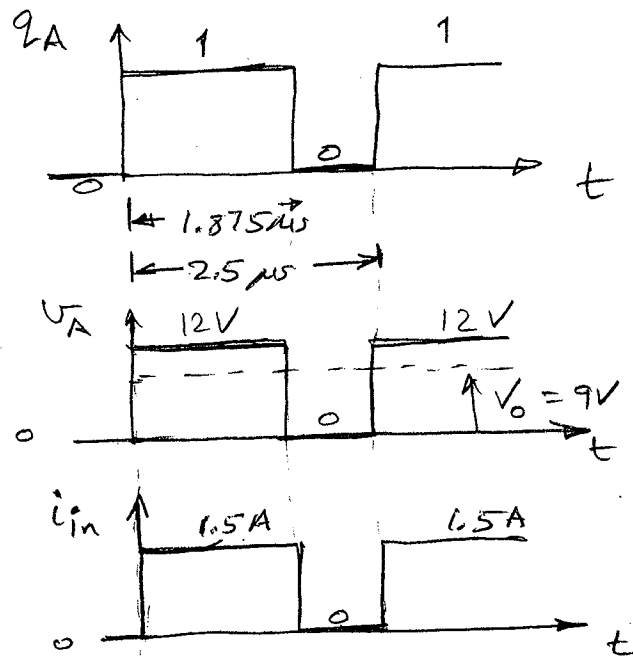
Using Eqs. 1-3 & 1-4

$$d_A = \frac{V_o}{V_{in}} = \frac{9}{12} = 0.75$$

$$\begin{aligned}\text{and, } T_{up} &= d_A T_s = d_A \left(\frac{1}{f_s} \right) \\ &= 1.875 \mu\text{s}\end{aligned}$$

Problem 1-24

from problem 1-15, $T_S = 2.5 \mu s$, $T_{up} = 6.875 \mu s$



Problem 1-25

$$V_{in} = 12V, \quad V_0 = 9V, \quad I_0 = \text{not given}$$

$\therefore$ Voltage dropped across the linear regulator $V_{reg} = 12 - 9 = 3V$

$$\therefore \eta_{max} = \frac{9V \times I_0}{12V \times I_0} = \frac{9}{12} = 75\%$$

1-26 Modify Lab Experiment-4 of PSpice
at www.cusp.umn.edu under
Power Electronics Course

1-27 Same as Prob 1-26 except
modify Lab Experiment-1.

Chapter 2

Problem 2-1

Similar to figs. 2-5 & 2-7.

Problem 2-2

$$P_{sw} = \frac{1}{2} V_{in} I_o (t_{c,on} + t_{c,off}) f_s$$

$$t_{c,on} = t_{ri} + t_{fv}$$

$$t_{c,off} = t_{rv} + t_{fi}$$

$$\therefore t_{c,on} + t_{c,off} = (20 + 15 + 20 + 15) \text{ ns} = 70 \text{ ns}$$

$$P_{sw} = \frac{1}{2} \times 42 \times 5 \times 70 \times 10^{-9} \times 400 \times 10^3 \text{ W}$$
$$= 2.94 \text{ W}$$

$$P_{in} = V_{in} I_{in}, \quad I_{in} = D I_o = 0.3 \times 5 = 1.5 \text{ A}$$

$$\therefore P_{in} = 42 \times 1.5 = 63 \text{ W}$$

$$\therefore \eta_{\text{due to } P_{sw}} = \frac{P_{in} - P_{sw}}{P_{in}} = \frac{63 - 2.94}{63} = 95.33\%$$

$\therefore$ 4.67% reduction in efficiency due to switching losses.

Problem 2-3

$$\begin{aligned} P_{\text{Cond}} &= d R_{\text{DS(on)}} I_o^2 & (2-3) \\ &= 0.3 \times 25 \times 10^{-3} \times 5^2 \\ &= 0.1875 \text{ W} \end{aligned}$$

Problem 2-4

$$\begin{aligned} P_{\text{discharge}} &= (1-d) V_{\text{FM}} I_o & (2A-1) \\ &= (1-0.3) \times 0.7 \times 5 \\ &= 2.45 \text{ W} \end{aligned}$$

Problem 2-5

$$t_a = 12 \text{ ns}, \quad t_{rr} = 20 \text{ ns}, \quad I_{\text{RRM}} = 2.5 \text{ A}$$

$$t_b = t_{rr} - t_a = (20 - 12) \text{ ns} = 8 \text{ ns}$$

$$V_{d, \text{neg}} = V_{\text{in}} = 42 \text{ V}$$

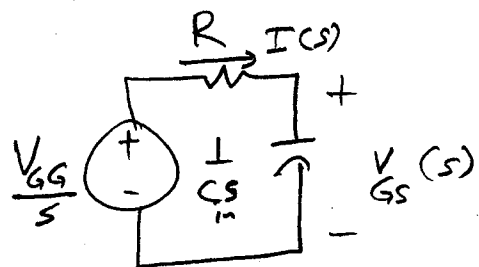
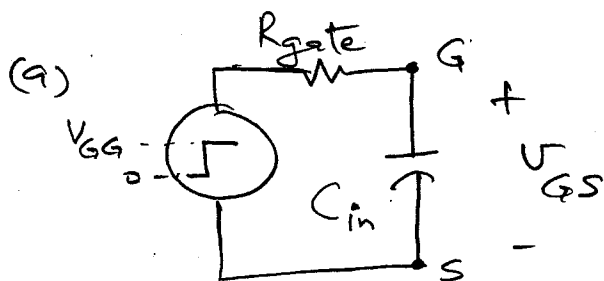
$$\begin{aligned} P_{\text{diode, sw}} &= \left(\frac{1}{2} I_{\text{RRM}} t_b \right) V_{d, \text{neg}} f_s \\ &= \frac{1}{2} \times 2.5 \times 8 \times 10^{-9} \times 42 \times 400 \times 10^3 \\ &= 0.168 \text{ W} \end{aligned}$$

Problem 2-6

$$V_{\text{ext}} = 12$$

$$\begin{aligned} P_{\text{gate drive}} &= V_{\text{ext}} Q_g f_s \\ &= 12 \times 40 \times 10^{-9} \times 400 \times 10^3 \\ &\approx 0.192 \text{ W} \end{aligned}$$

Problem 2-7



$$I(s) = \frac{V_{GG}}{s} \frac{1}{R + \frac{1}{sC_{in}}} ; V_{GS}(s) = \frac{V_{GG}}{s} \frac{(1/RC_{in})}{(s + 1/RC_{in})}$$

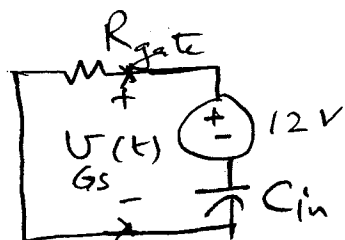
$$\therefore V_{GS}(t) = V_{GG} (1 - e^{-t/(RC_{in})})$$

(a) $V_{GS(th)} = 2.5 \text{ V} \Rightarrow t = t_{d(on)}$

$$\therefore 3.0 = 12 (1 - e^{-t_{d(on)}/(RC_{in})})$$

$$\therefore t_{d(on)} = 6.78 \text{ ns}$$

(b)



$$V_{GS}(t) = V_{GG} e^{-t/(RC_{in})}$$

for $V_{GS(I_0)} = 4.25 \text{ V}$

$$t_{d(off)} = 20.28 \text{ ns}$$

Problem 2-8

$$P_{sw} = 2.94 \text{ W} \quad (\text{problem 2-2})$$

$$P_{cond} = 0.1875 \quad (\text{problem 2-3})$$

$$P_{total} = P_{sw} + P_{cond} = 3.1275$$

$$T_j = T_a + (R_{\theta jc} + R_{\theta cs} + R_{\theta sa}) P_{diss} \quad (2-7)$$

$$100^\circ\text{C} = 40^\circ\text{C} + (1.3 + 1.9 + R_{\theta sa}) \times 3.1275$$

$$\begin{aligned} \therefore R_{\theta sa} &= \frac{100 - 40}{3.1275} - (1.3 + 1.9) \\ &= 15.98^\circ\text{C/W} \end{aligned}$$

Problem 2-9

Modify Lab Experiment-3 at
www.cusp.cmn.edu under Power
Electronics course.

Chapter 3

Problem 3-1

$$V_{in} = 42 \text{ V}, \quad V_o = D V_{in} = 12.6 \text{ V}$$

$$f_s = 400 \text{ kHz}, \quad T_s = 2.5 \mu\text{s}$$

$$P_o = 24 \text{ W} \quad \therefore I_o = \frac{P_o}{V_o} = 1.905 \text{ A}$$

$$\Delta I_L = \frac{(42 - 12.6) \times 0.3 \times 2.5 \mu\text{s}}{2.5 \mu\text{s}} = 0.882 \text{ A}$$

(See fig. 3-5d)

Problem 3-2

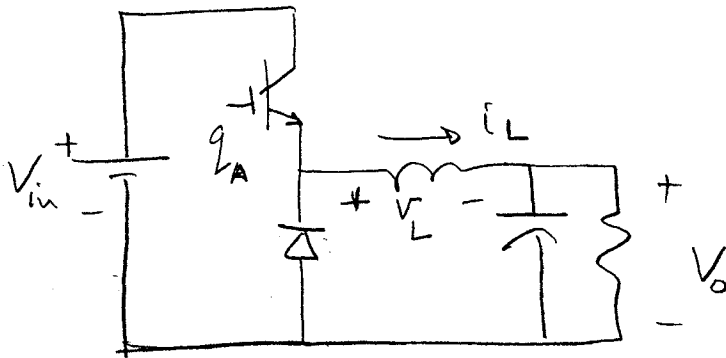
$$\text{At } P_o = 12 \text{ W}, \quad I_o = I_L = \frac{P_o}{V_o} = \frac{12}{12.6} = 0.952 \text{ A}$$

From Problem 3-1, in CCM, $\Delta I_L (p-p) = 0.882 \text{ A}$

Since $\frac{\Delta I_L (p-p)}{2}$ is less than I_o of 0.952 A ,
this converter would continue to operate
in CCM.

$$\Delta I_L = 0.882 \text{ A} \quad (\text{as before}).$$

Problem 3-3



$$D = 0.3$$

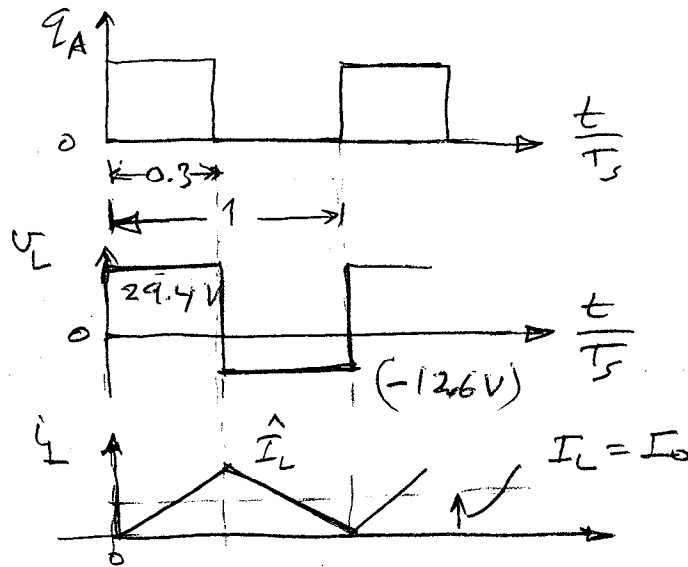
$$V_O = D V_{in}$$

$$= 0.3 \times 42$$

$$= 12.6 \text{ V}$$

$$V_L = +29.4 \text{ V or } -12.6 \text{ V}$$

$$f_s = 400 \text{ kHz}$$



$$\hat{I}_{L, \text{crit}} = \frac{1}{L} (V_{in} - V_O) D T_s$$

$$= \frac{(42 - 12.6)}{25 \mu} \cdot 0.3 \times 2.5 \mu$$

$$= 0.882 \text{ A}$$

$$I_{O, \text{crit}} = \frac{1}{2} \hat{I}_{L, \text{crit}} = 0.441 \text{ A}$$

$$\therefore P_{O, \text{crit}} = V_O I_{O, \text{crit}} = 12.6 \times 0.441$$

$$= 5.557 \text{ W}$$

Problem 3-4

$$V_{in} = 24V \text{ to } 50V$$

at the border of CCM/DCM -

During $(1-D)T_s$,

$$L \frac{\hat{I}_L}{(1-D)T_s} = V_o$$

$$\hat{I}_L = 2(I_o) = 2\left(\frac{P_o}{V_o}\right)$$

$$\therefore L = \frac{V_o (1-D) T_s}{2 P_o / V_o}$$

$$P_o = P_{o, \min} = 5W$$

$$= \frac{1}{2 P_o} V_o^2 (1-D) T_s$$

Maximum L is needed at the highest V_o

$$V_o, \max = D V_{in, \max} = 15V$$

$$\therefore L = \frac{1}{2 \times 5} 15^2 (1-0.3) \times 2.5 \mu s$$

$$\approx 39.4 \mu H$$

Problem 3-5

$$\Delta I_L = 0.882 \text{ A}$$

at the border of CCM/DCM

$$I_o = I_L = \frac{\Delta I_L (p-p)}{2} = \frac{0.882 \text{ A}}{2} = 0.441 \text{ A}$$

Similar voltage waveforms as in
Problem 3-1 & 3-2.

Problem 3-6

$$V_{in} = 24 - 50 \text{ V}$$

$D = \text{adjusted}$

$$V_o = 0.3 \times 40 = 12 \text{ V (held constant)}$$

$$P_o = 5 \text{ W}$$

$$L = ?$$

From Problem 3-4

$$L = \frac{1}{2P_o} V_o^2 (1-D) T_s$$

maximum L is needed at the smallest D or the highest V_{in} -

$$D_{\max} = \frac{V_o}{V_{in, \max}} = \frac{12}{50} = 0.24$$

$$\therefore L = \frac{1}{2 \times 5} 12^2 (1 - 0.24) \times 2.5 \mu$$

$$\approx 27.4 \mu \text{H}$$