Electric Circuits 12th edition Nilsson Solutions Manual

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1
Circuit Variables

Assessment Problems

AP 1.1 Use a product of ratios to convert 95% of the speed of light from meters per second to miles per second:

$$(0.95)\,\frac{3\times 10^8\ \text{m}}{1\ \text{s}}\cdot\frac{100\ \text{cm}}{1\ \text{m}}\cdot\frac{1\ \text{in}}{2.54\ \text{cm}}\cdot\frac{1\ \text{ft}}{12\ \text{in}}\cdot\frac{1\ \text{mile}}{5280\ \text{feet}}=\frac{177{,}090.79\ \text{miles}}{1\ \text{s}}.$$

Now set up a proportion to determine how long it takes this signal to travel 950 miles:

$$\frac{177{,}090.79\ \text{miles}}{1\ \text{s}}=\frac{950\ \text{miles}}{x\ \text{s}}.$$

Therefore,

$$x=\frac{950}{177{,}090.79}=0.00536=5.36\times 10^{-3}\ \text{s}=5.36\ \text{ms}.$$

AP 1.2 We begin by expressing \$1 trillion in scientific notation:

$$\$1\ \text{trillion}\ =\$1\times 10^{12}.$$

Divide by $100 = 10^2$ to find the number of \$100 bills:

$$\$1\ \text{trillion}\ =\frac{10^{12}}{10^2}=10^{10}\ \$100\ \text{bills}.$$

Calculate the height of a stack of 10^{10} \$100 bills:

$$10^{10}\ \text{bills}\cdot\frac{0.11\ \text{mm}}{\text{bill}}\cdot\frac{1\ \text{m}}{1000\ \text{mm}}=1.1\times 10^6\ \text{m}.$$

Now we can convert from meters to miles, again with a product of ratios:

$$1.1\times 10^6\ \text{m}\cdot\frac{100\ \text{cm}}{1\ \text{m}}\cdot\frac{1\ \text{in}}{2.54\ \text{cm}}\cdot\frac{1\ \text{ft}}{12\ \text{in}}\cdot\frac{1\ \text{mi}}{5280\ \text{ft}}=683.51\ \text{miles}.$$

AP 1.3 **[a]** First we use Eq. (1.2) to relate current and charge:

$$i = \frac{dq}{dt} = 0.25te^{-2000t}.$$

Therefore, $dq = 0.25te^{-2000t}\,dt$.

To find the charge, we can integrate both sides of the last equation. Note that we substitute x for q on the left side of the integral, and y for t on the right side of the integral:

$$\int_{q(0)}^{q(t)} dx = 0.25\int_0^t ye^{-2000y}\,dy.$$

We solve the integral and make the substitutions for the limits of the integral:

$$q(t) - q(0) = 0.25\frac{e^{-2000y}}{(-2000)^2}(-2000y - 1)\Big|_0^t$$

$$= 62.5\times 10^{-9}e^{-2000t}(-2000t - 1) + 62.5\times 10^{-9}$$

$$= 62.5\times 10^{-9}(1 - 2000te^{-2000t} - e^{-2000t}).$$

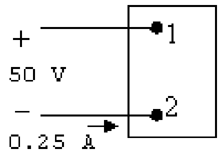
But $q(0) = 0$ by hypothesis, so

$$q(t) = 62.5(1 - 2000te^{-2000t} - e^{-2000t})\text{ nC}.$$

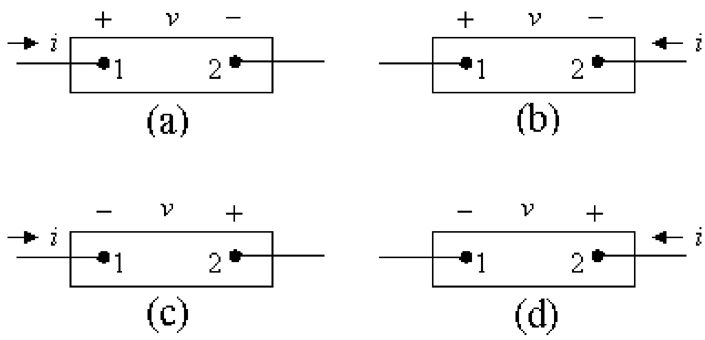
[b] $q(0.001) = (62.5)[1 - 2000(0.001)e^{-2000(0.001)} - e^{-2000(0.001)}] = 37.12$ nC.

AP 1.4 $n = \dfrac{75\times 10^{-6}\text{ C/s}}{1.6022\times 10^{-19}\text{ C/elec}} = 4.681\times 10^{14}$ elec/s.

AP 1.5 Start by drawing a picture of the circuit described in the problem statement:



Also sketch the four figures from Fig. 1.6:



[a] Now we have to match the voltage and current shown in the first figure with the polarities shown in Fig. 1.6. Remember that 250 mA of current entering Terminal 2 is the same as 250 mA of current leaving Terminal 1. We get

(a) $v = 50\,\mathrm{V}, \quad i = -0.25\,\mathrm{A}$; (b) $v = 50\,\mathrm{V}, \quad i = 0.25\,\mathrm{A}$;

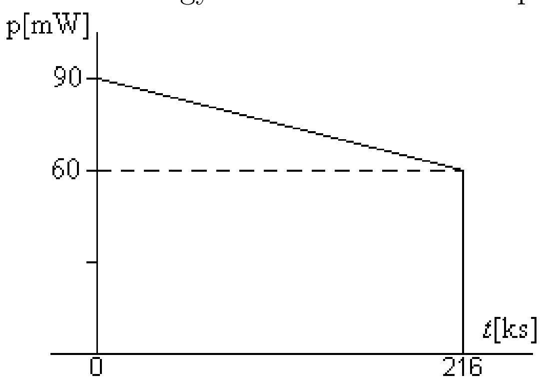
(c) $v = -50\,\mathrm{V}, \quad i = -0.25\,\mathrm{A}$; (d) $v = -50\,\mathrm{V}, \quad i = 0.25\,\mathrm{A}$.

[b] Using the reference system in Fig. 1.6(a) and the passive sign convention, $p = vi = (50)(-0.25) = -12.5\,\mathrm{W}$.

[c] Since the power is less than 0, the box is delivering power.

AP 1.6 $p = vi; \qquad w = \int_0^t p\,dx.$

Since the energy is the area under the power vs. time plot, let us plot p vs. t.



Note that in constructing the plot above, we used the fact that 60 hr = 216,000 s = 216 ks.

$$p(0) = (6)(15 \times 10^{-3}) = 90 \times 10^{-3}\ \mathrm{W};$$

$$p(216\ \mathrm{ks}) = (4)(15 \times 10^{-3}) = 60 \times 10^{-3}\ \mathrm{W};$$

$$w = (60 \times 10^{-3})(216 \times 10^3) + \frac{1}{2}(90 \times 10^{-3} - 60 \times 10^{-3})(216 \times 10^3) = 16{,}200\ \mathrm{J}.$$

AP 1.7 [a] $p = vi = (15e^{-250t})(0.04e^{-250t}) = 0.6e^{-500t}$ W;

$$p(0.01) = 0.6e^{-500(0.01)} = 0.6e^{-5} = 0.00404 = 4.04\ \mathrm{mW}.$$

[b] $$w_{\text{total}} = \int_0^\infty p(x)\,dx = \int_0^\infty 0.6e^{-500x}\,dx = \frac{0.6}{-500}e^{-500x}\Big|_0^\infty$$

$$= -0.0012(e^{\infty} - e^0) = 0.0012 = 1.2\ \mathrm{mJ}.$$

Chapter Problems

P 1.1 **[a]** Use a product of ratios to convert 40,075 km to inches:

$$40{,}075\text{ km}\cdot\frac{1000\text{ m}}{1\text{ km}}\cdot\frac{100\text{ cm}}{1\text{ m}}\cdot\frac{1\text{ in}}{2.54\text{ cm}}=1{,}577{,}755{,}905.5\text{ in.}$$

Now calculate the number of \$20 bills this distance represents:

$$\text{Number of bills}\;=\frac{1{,}577{,}755{,}905.5\text{ in}}{6.14\text{ in/bill}}=256{,}963{,}502.5\approx 256{,}963{,}503.$$

The total dollar amount represented by this number of \$20 bills is

$$\text{Total dollars}\;=(256{,}963{,}503)(\$20)\approx \$5.14\text{ billion.}$$

[b] The weight of the number of bills calculated in part (a) is (256,963,503)(1 g) = 256,963.5 kg. Use a product of ratios to convert kg to tons:

$$256{,}963.5\text{ kg}\cdot\frac{2.2\text{ lbs}}{1\text{ kg}}\cdot\frac{1\text{ ton}}{2000\text{ lbs}}=282.66\text{ tons.}$$

P 1.2 **[a]** $8(65.5\times10^6)\text{ bits}\cdot\dfrac{1\text{ s}}{50\times10^6\text{ bits}}=10.48\text{ s.}$

[b] $8(65.5\times10^6)\text{ bits}\cdot\dfrac{1\text{ s}}{2\times10^9\text{ bits}}=262\text{ ms.}$

[c] $8(74\times10^{12})\text{ bits}\cdot\dfrac{1\text{ s}}{50\times10^6\text{ bits}}=11.84\times10^6\text{ s}$

$$11.84\times10^6\text{ s}\cdot\frac{1\text{ min}}{60\text{ s}}\cdot\frac{1\text{ hr}}{60\text{ min}}\cdot\frac{1\text{ day}}{24\text{ hr}}=137\text{ days!}$$

[d] $8(74\times10^{12})\text{ bits}\cdot\dfrac{1\text{ s}}{2\times10^9\text{ bits}}=296\times10^3\text{ s.}$

$$296\times10^3\text{ s}\cdot\frac{1\text{ min}}{60\text{ s}}\cdot\frac{1\text{ hr}}{60\text{ min}}\cdot\frac{1\text{ day}}{24\text{ hr}}=3.4\text{ days.}$$

P 1.3 **[a]** To begin, we calculate the number of pixels that make up the display:

$$n_{\text{pixels}}=(1920)(1080)=2{,}073{,}600\text{ pixels.}$$

Each pixel requires 24 bits of information. Since 8 bits equal one byte, each pixel requires 3 bytes of information. We can calculate the number of bytes of information required for the display by multiplying the number of pixels in the display by 3 bytes per pixel:

$$n_{\text{bytes}}=\frac{2{,}073{,}600\text{ pixels}}{1\text{ display}}\cdot\frac{3\text{ bytes}}{1\text{ pixel}}=6{,}220{,}800\text{ bytes/display.}$$

Finally, we use the fact that there are 10^6 bytes per MB:

$$\frac{6{,}220{,}800 \text{ bytes}}{1 \text{ display}} \cdot \frac{1 \text{ MB}}{10^6 \text{ bytes}} = 6.22 \text{ MB/display}.$$

[b] $$\frac{6{,}220{,}800 \text{ bytes}}{10 \text{ ms}} \cdot \frac{8 \text{ bits}}{1 \text{ byte}} = 4.98 \text{ Gbps}.$$

[c] Convert the dimensions of the monitor from inches to mm:

$$24 \text{ in} \cdot \frac{25.4 \text{ mm}}{1 \text{ in}} = 609.6 \text{ mm}.$$

$$14 \text{ in} \cdot \frac{25.4 \text{ mm}}{1 \text{ in}} = 355.6 \text{ mm}.$$

Calculate the area of the monitor in mm^2:

$$\text{Screen area } = (609.6)(355.6) = 126{,}773.76 \text{ mm}^2.$$

Divide the area of the monitor by the number of pixels in the monitor to find the area of an indiviual pixel:

$$\frac{126{,}773.76 \text{ mm}^2}{2{,}073{,}600 \text{ pixels}} = 0.1045 \text{ mm}^2\text{/pixel}.$$

P 1.4 $$\frac{(1024)(600) \text{ pixels}}{1 \text{ frame}} \cdot \frac{3 \text{ bytes}}{1 \text{ pixel}} \cdot \frac{60 \text{ frames}}{1 \text{ sec}} = 110{,}592 \times 10^3 \text{ bytes/sec;}$$

$$(110{,}592 \times 10^3 \text{ bytes/sec})(x \text{ secs}) = 128 \times 10^9 \text{ bytes;}$$

$$x = \frac{128 \times 10^9}{110{,}592 \times 10^3} = 1157 \text{ sec} = 19.3 \text{ min of video.}$$

P 1.5 $$\frac{(0.8)(5.4 \times 10^6)(1.5 \times 10^3) + (0.9)(1.4 \times 10^6)(45 \times 10^3)}{10^9} = 63.18 \text{ GWh}.$$

P 1.6 **[a]** $$(0.6)(64 \text{ kWh}) \cdot \frac{100 \text{ km}}{16 \text{ kWh}} = 240 \text{ km;}$$

$$240 \text{ km} \cdot \frac{0.62 \text{ mi}}{1 \text{ km}} = 148.8 \text{ mi}.$$

[b] $$200 \text{ mi} \cdot \frac{1 \text{ km}}{0.62 \text{ mi}} = 322.58 \text{ km;}$$

$$\frac{100 \text{ km}}{16 \text{ kWh}} = \frac{322.58 \text{ km}}{x \text{ kWh}} \quad \text{so} \quad x = \frac{322.58(16)}{100} = 51.61 \text{ kWh}.$$

$$\frac{51.61 \text{ kWh}}{64 \text{ kWh}}(100) \approx 81\%.$$

P 1.7 Remember from Eq. 1.2, current is the time rate of change of charge, or $i = \frac{dq}{dt}$ In this problem, we are given the current and asked to find the total charge. To do this, we must integrate Eq. 1.2 to find an expression for charge in terms of current:

$$q(t) = \int_0^t i(x)\,dx.$$

We are given the expression for current, i, which can be substituted into the above expression. To find the total charge, we let $t \to \infty$ in the integral. Thus we have

$$q_{\text{total}} = \int_0^\infty 20e^{-5000x}\,dx = \frac{20}{-5000}e^{-5000x}\Big|_0^\infty = \frac{20}{-5000}(e^{-\infty} - e^0)$$
$$= \frac{20}{-5000}(0-1) = \frac{20}{5000} = 0.004\ \text{C} = 4000\,\mu\text{C}.$$

P 1.8 **[a]** First we use Eq. 1.2 to relate current and charge:

$$i = \frac{dq}{dt} = 0.025e^{-1000t}.$$

Therefore, $dq = 0.025e^{-1000t}\,dt$.

To find the charge, we can integrate both sides of the last equation. Note that we substitute x for q on the left side of the integral, and y for t on the right side of the integral:

$$\int_{q(0)}^{q(t)} dx = 0.025\int_0^t e^{-1000y}\,dy.$$

We solve the integral and make the substitutions for the limits of the integral:

$$q(t) - q(0) = 0.025\frac{e^{-1000y}}{-1000}\Big|_0^t = 25\times10^{-6}(1 - e^{-1000t}).$$

But $q(0) = 0$ by hypothesis, so

$$q(t) = 25(1 - e^{-1000t})\,\mu\text{C}.$$

[b] As $t \to \infty$, $q_T = 25\,\mu$C.

[c] $q(1\times10^{-3}) = (25\times10^{-6})(1 - e^{(-1000)(0.001)}) = 15.8\,\mu$C.

P 1.9 First we use Eq. 1.2 to relate current and charge:

$$i = \frac{dq}{dt} = 0.1\cos 2500t.$$

Therefore, $dq = 0.1\cos 2500t\,dt$.

To find the charge, we can integrate both sides of the last equation. Note that we substitute x for q on the left side of the integral, and y for t on the right side of the integral:

$$\int_{q(0)}^{q(t)} dx = 0.1 \int_0^t \cos 2500y \, dy.$$

We solve the integral and make the substitutions for the limits of the integral, remembering that $\sin 0 = 0$:

$$q(t) - q(0) = 0.1 \frac{\sin 2500y}{2500} \Big|_0^t = \frac{0.1}{2500} \sin 2500t - \frac{0.1}{2500} \sin[2500(0)] = \frac{0.1}{2500} \sin 2500t.$$

But $q(0) = 0$ by hypothesis, i.e., the current passes through its maximum value at $t = 0$, so $q(t) = 40 \times 10^{-6} \sin 2500t \, \mathrm{C} = 40 \sin 2500t \, \mu\mathrm{C}$.

P 1.10 $w = qV = (1.6022 \times 10^{-19})(9) = 14.42 \times 10^{-19} = 1.442$ aJ.

P 1.11 Recall from Eq. 1.2 that current is the time rate of change of charge, or $i = \frac{dq}{dt}$. In this problem we are given an expression for the charge, and asked to find the maximum current. First we will find an expression for the current using Eq. 1.2:

$$\begin{aligned}
i = \frac{dq}{dt} &= \frac{d}{dt}\left[\frac{1}{\alpha^2} - \left(\frac{t}{\alpha} + \frac{1}{\alpha^2}\right) e^{-\alpha t}\right] \\
&= \frac{d}{dt}\left(\frac{1}{\alpha^2}\right) - \frac{d}{dt}\left(\frac{t}{\alpha} e^{-\alpha t}\right) - \frac{d}{dt}\left(\frac{1}{\alpha^2} e^{-\alpha t}\right) \\
&= 0 - \left(\frac{1}{\alpha} e^{-\alpha t} - \alpha \frac{t}{\alpha} e^{-\alpha t}\right) - \left(-\alpha \frac{1}{\alpha^2} e^{-\alpha t}\right) \\
&= \left(-\frac{1}{\alpha} + t + \frac{1}{\alpha}\right) e^{-\alpha t} \\
&= t e^{-\alpha t}.
\end{aligned}$$

Now that we have an expression for the current, we can find the maximum value of the current by setting the first derivative of the current to zero and solving for t:

$$\frac{di}{dt} = \frac{d}{dt}(t e^{-\alpha t}) = e^{-\alpha t} + t(-\alpha) e^{-\alpha t} = (1 - \alpha t) e^{-\alpha t} = 0.$$

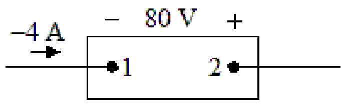
Since $e^{-\alpha t}$ never equals 0 for a finite value of t, the expression equals 0 only when $(1 - \alpha t) = 0$. Thus, $t = 1/\alpha$ will cause the current to be maximum. For this value of t, the current is

$$i = \frac{1}{\alpha} e^{-\alpha/\alpha} = \frac{1}{\alpha} e^{-1}.$$

Remember in the problem statement, $\alpha = 0.03679$. Using this value for α,

$$i = \frac{1}{0.03679}e^{-1} \cong 10 \text{ A}.$$

P 1.12 [a]



$p = vi = -(80)(-4) = 320$ W.
Power is being absorbed by the box.

[b] Entering.

[c] Gain.

P 1.13 [a] $p = -vi = -(80)(4) = -320$ W, so power is being delivered by the box.

[b] Leaving.

[c] Lose.

P 1.14 [a] In Car A, the current i is in the direction of the voltage drop across the 12 V battery(the current i flows into the + terminal of the battery of Car A). Therefore using the passive sign convention,
$p = vi = (25)(12) = 300$ W.
Since the power is positive, the battery in Car A is absorbing power, so Car A must have the "dead" battery.

[b] $w(t) = \int_0^t p\,dx; \qquad 1 \text{ min} = 1 \cdot \frac{60 \text{ s}}{1 \text{ min}} = 60 \text{ s};$

$$w(60) = \int_0^{60} 300\,dx;$$

$$w = 300(60 - 0) = 300(60) = 18{,}000 \text{ J} = 18 \text{ kJ}.$$

P 1.15 Assume we are standing at box A looking toward box B. Use the passive sign convention to get $p = -vi$, since the current i is flowing out of the + terminal of the voltage v. Now we just substitute the values for v and i into the equation for power. Remember that if the power is positive, B is absorbing power, so the power must be flowing from A to B. If the power is negative, B is generating power so the power must be flowing from B to A.

[a] $p = -(-20)(0.15) = 3$ W 3 W from A to B;

[b] $p = -(40)(15) = -600$ W 600 W from B to A;

[c] $p = -(-2000)(-0.05) = -100$ W 100 W from B to A;

[d] $p = -(80)(-3) = 240$ W 240 W from A to B.

P 1.16 $p = (9)(0.15) = 1.35$ W; $\quad 3 \text{ hr} \cdot \dfrac{3600 \text{ s}}{1 \text{ hr}} = 10{,}800$ s;

$$w(t) = \int_0^t p\,dt; \qquad w(10{,}800) = \int_0^{10{,}800} 1.35\,dt = 1.35(10{,}800) = 14.58 \text{ kJ}.$$

P 1.17 At the Building X end of the line the current is leaving the upper terminal, and thus entering the lower terminal where the polarity marking of the voltage is negative. Thus, using the passive sign convention, $p = -vi$. Substituting the values of voltage and current given in the figure,

$$p = -(800 \times 10^3)(1.8 \times 10^3) = -1440 \times 10^6 = -1440 \text{ MW}.$$

Thus, because the power associated with the Building X end of the line is negative, power is being generated at the Building X end of the line and transmitted by the line to be delivered to the Building Y end of the line.

P 1.18 **[a]** Applying the passive sign convention to the power equation using the voltage and current polarities shown in Fig. 1.5, $p = vi$.

$$p(t) = (80{,}000te^{-500t})(15te^{-500t}) = 120 \times 10^4 t^2 e^{-1000t};$$

$$p(0.01) = 120 \times 10^4 (0.01)^2 e^{-1000(0.01)} = 5.45 \text{ mW}.$$

[b] We know that power is the time rate of change of energy, or $p = dw/dt$. If we know the power, we can find the energy by integrating Eq. 1.3. To find the total energy, the upper limit of the integral is infinity:

$$\begin{aligned} w_{\text{total}} &= \int_0^\infty 120 \times 10^4 x^2 e^{-1000x}\,dx \\ &= \frac{120 \times 10^4}{(-1000)^3} e^{-1000x}[(-1000)^2x^2 - 2(-1000)x + 2)\Big|_0^\infty \\ &= 0 - \frac{120 \times 10^4}{(-1000)^3} e^0(0 - 0 + 2) = 2.4 \text{ mJ}. \end{aligned}$$

P 1.19 **[a]** $p = vi = (100e^{-500t})(0.02 - 0.02e^{-500t}) = (2e^{-500t} - 2e^{-1000t})$ W;

$$\frac{dp}{dt} = -1000e^{-500t} + 2000e^{-1000t} = 0 \qquad \text{so} \qquad 2e^{-1000t} = e^{-500t};$$

$2 = e^{500t}$ so $\ln 2 = 500t$ thus p is maximum at t = 1.4 ms;

$$p_{\max} = p(1.4 \text{ ms}) = 0.5 \text{ W}.$$

[b] $w = \displaystyle\int_0^\infty [2e^{-500t} - 2e^{-1000t}]\,dt = \left[\frac{2}{-500}e^{-500t} - \frac{2}{-1000}e^{-1000t}\Big|_0^\infty\right]$

$$= \frac{4}{1000} - \frac{2}{1000} = 2 \text{ mJ}.$$

P 1.20 **[a]** We can find the time at which the power is a maximum by writing an expression for $p(t) = v(t)i(t)$, taking the first derivative of $p(t)$ and setting it to zero, then solving for t. The calculations are shown below:

$$\begin{aligned}
p &= 0 \quad t < 0, \qquad p = 0 \quad t > 3 \text{ s};\\
p &= vi = t(3-t)(6-4t) = 18t - 18t^2 + 4t^3 \text{ mW} \qquad 0 \le t \le 3 \text{ s};\\
\frac{dp}{dt} &= 18 - 36t + 12t^2 = 12(t^2 - 3t + 1.5);\\
\frac{dp}{dt} &= 0 \qquad \text{when } t^2 - 3t + 1.5 = 0;\\
t &= \frac{3 \pm \sqrt{9-6}}{2} = \frac{3 \pm \sqrt{3}}{2};\\
t_1 &= 3/2 - \sqrt{3}/2 = 0.634 \text{ s}; \qquad t_2 = 3/2 + \sqrt{3}/2 = 2.366 \text{ s}.\\
p(t_1) &= 18(0.634) - 18(0.634)^2 + 4(0.634)^3 = 5.196 \text{ mW};\\
p(t_2) &= 18(2.366) - 18(2.366)^2 + 4(2.366)^3 = -5.196 \text{ mW}.
\end{aligned}$$

Therefore, maximum power is being delivered at $t = 0.634$ s.

[b] The maximum power was calculated in part (a) to determine the time at which the power is maximum: $p_{\text{max}} = 5.196$ mW (delivered).

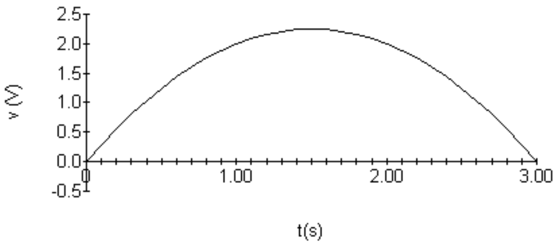
[c] As we saw in part (a), the other “maximum” power is actually a minimum, or the maximum negative power. As we calculated in part (a), maximum power is being extracted at $t = 2.366$ s.

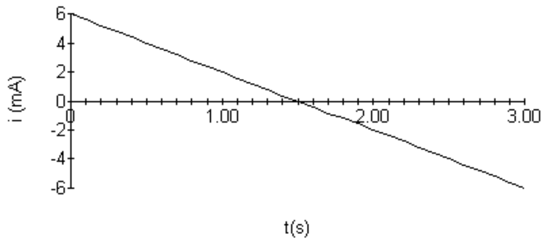
[d] This maximum extracted power was calculated in part (a) to determine the time at which power is maximum: $p_{\text{max}} = 5.196$ mW (extracted).

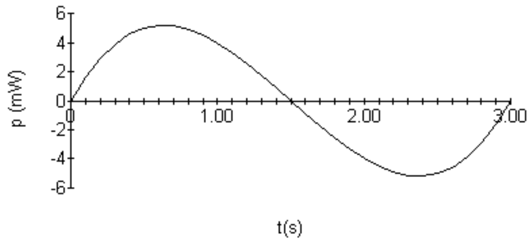
[e] $w = \int_0^t p\,dx = \int_0^t (18x - 18x^2 + 4x^3)\,dx = 9t^2 - 6t^3 + t^4.$

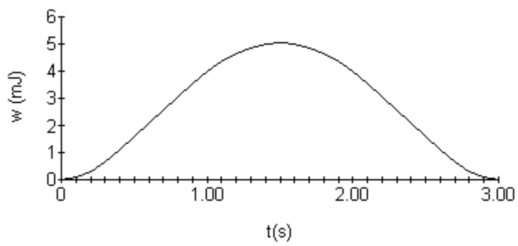
$$\begin{aligned}
w(0) &= 0 \text{ mJ}; \qquad & w(2) &= 4 \text{ mJ};\\
w(1) &= 4 \text{ mJ}; \qquad & w(3) &= 0 \text{ mJ}.
\end{aligned}$$

To give you a feel for the quantities of voltage, current, power, and energy and their relationships among one another, they are plotted below:









P 1.21 **[a]** $p = vi = (16{,}000t + 20)e^{-800t}][(128t + 0.16)e^{-800t}]$

$$= 2048 \times 10^3 t^2 e^{-1600t} + 5120te^{-1600t} + 3.2e^{-1600t}$$

$$= 3.2e^{-1600t}[640{,}000t^2 + 1600t + 1];$$

$$\frac{dp}{dt} = 3.2\{e^{-1600t}[1280 \times 10^3 t + 1600] - 1600e^{-1600t}[640{,}000t^2 + 1600t + 1]\}$$

$$= -3.2e^{-1600t}[128 \times 10^4(800t^2 + t)] = -409.6 \times 10^4 e^{-1600t} t(800t + 1).$$

Therefore, $\frac{dp}{dt} = 0$ when $t = 0$ so $p_{\max}$ occurs at $t = 0$.

[b] $p_{\max} = 3.2e^{-0}[0 + 0 + 1] = 3.2$ W.

[c] $w = \int_0^t p\,dx;$

$$\frac{w}{3.2} = \int_0^t 640{,}000x^2 e^{-1600x}\,dx + \int_0^t 1600xe^{-1600x}\,dx + \int_0^t e^{-1600x}\,dx$$

$$= \frac{640{,}000e^{-1600x}}{-4096\times 10^6}[256\times 10^4x^2 + 3200x + 2]\Big|_0^t$$

$$+ \frac{1600e^{-1600x}}{256\times 10^4}(-1600x - 1)\Big|_0^t + \frac{e^{-1600x}}{-1600}\Big|_0^t.$$

When $t \to \infty$ all the upper limits evaluate to zero, hence

$$\frac{w}{3.2} = \frac{(640{,}000)(2)}{4096\times 10^6} + \frac{1600}{256\times 10^4} + \frac{1}{1600};$$

$w = 10^{-3} + 2\times 10^{-3} + 2\times 10^{-3} = 5$ mJ.

P 1.22 **[a]** $p = vi = 30e^{-500t} - 30e^{-1500t} - 40e^{-1000t} + 50e^{-2000t} - 10e^{-3000t};$
$p(1\text{ ms}) = 3.1$ mW.

[b]

$$\begin{aligned} w(t) &= \int_0^t (30e^{-500x} - 30e^{-1500x} - 40e^{-1000x} \\ &\quad + 50e^{-2000x} - 10e^{-3000x})dx \\ &= 21.67 - 60e^{-500t} + 20e^{-1500t} + 40e^{-1000t} \\ &\quad - 25e^{-2000t} + 3.33e^{-3000t}\,\mu\text{J}; \\ w(1\text{ ms}) &= 1.24\,\mu\text{J}. \end{aligned}$$

[c] $w_{\text{total}} = 21.67\,\mu$J.

P 1.23 **[a]**

$$\begin{aligned} p &= vi = (10^4t + 5)e^{-400t}][(40t + 0.05)e^{-400t}] \\ &= 400\times 10^3t^2e^{-800t} + 700te^{-800t} + 0.25e^{-800t} \\ &= e^{-800t}[400{,}000t^2 + 700t + 0.25]; \\ \frac{dp}{dt} &= \{e^{-800t}[800\times 10^3t + 700] - 800e^{-800t}[400{,}000t^2 + 700t + 0.25]\} \\ &= [-3{,}200{,}000t^2 + 2400t + 5]100e^{-800t}. \end{aligned}$$

Therefore, $\dfrac{dp}{dt} = 0$ when $3{,}200{,}000t^2 - 2400t - 5 = 0$
so $p_{\max}$ occurs at $t = 1.68$ ms.

[b]

$$\begin{aligned} p_{\max} &= [400{,}000(.00168)^2 + 700(.00168) + 0.25]e^{-800(.00168)} \\ &= 0.67\text{ W}. \end{aligned}$$

[c]
$$w = \int_0^t p\,dx;$$
$$w = \int_0^t 400{,}000x^2e^{-800x}\,dx + \int_0^t 700xe^{-800x}\,dx + \int_0^t 0.25e^{-800x}\,dx$$
$$= \frac{400{,}000e^{-800x}}{-512\times10^6}[64\times10^4x^2+1600x+2]\Big|_0^t + \frac{700e^{-800x}}{64\times10^4}(-800x-1)\Big|_0^t + 0.25\frac{e^{-800x}}{-800}\Big|_0^t.$$

When $t\to\infty$ all the upper limits evaluate to zero, hence
$$w = \frac{(400{,}000)(2)}{512\times10^6} + \frac{700}{64\times10^4} + \frac{0.25}{800} = 2.97 \text{ mJ}.$$

P 1.24 [a] $v(10\text{ ms}) = 400e^{-1}\sin 2 = 133.8$ V;
$i(10\text{ ms}) = 5e^{-1}\sin 2 = 1.67$ A;
$p(10\text{ ms}) = v(10\text{ ms})i(10\text{ ms}) = 223.79$ W.

[b]
$$p = vi = 2000e^{-200t}\sin^2 200t$$
$$= 2000e^{-200t}\left[\frac{1}{2}-\frac{1}{2}\cos 400t\right]$$
$$= 1000e^{-200t} - 1000e^{-200t}\cos 400t;$$
$$w = \int_0^\infty 1000e^{-200t}\,dt - \int_0^\infty 1000e^{-200t}\cos 400t\,dt$$
$$= 1000\left.\frac{e^{-200t}}{-200}\right|_0^\infty - 1000\left\{\frac{e^{-200t}}{(200)^2+(400)^2}[-200\cos 400t + 400\sin 400t]\right\}\Bigg|_0^\infty$$
$$= 5 - 1000\left[\frac{200}{4\times10^4+16\times10^4}\right] = 5-1 = 4 \text{ J}.$$

P 1.25 [a] $p = vi = 900\sin(200\pi t)\cos(200\pi t) = 450\sin(400\pi t)$ W.
Therefore, $p_{\max} = 450$ W.

[b] $p_{\max}(\text{extracting}) = 450$ W.

[c]
$$p_{\text{avg}} = \frac{1}{0.005}\int_0^{5\times10^{-3}} 450\sin(400\pi t)\,dt$$
$$= 9\times10^4\left[\frac{-\cos 400\pi t}{400\pi}\right]_0^{5\times10^{-3}} = \frac{225}{\pi}[1-\cos 2\pi] = 0.$$

[d]
$$p_{\text{avg}} = \frac{1}{0.00625}\int_0^{6.25\times10^{-3}} 450\sin(400\pi t)\,dt$$
$$= \frac{180}{\pi}[1-\cos 2.5\pi] = \frac{180}{\pi} = 57.3 \text{ W}.$$

P 1.26 [a]
$$q = \text{area under } i \text{ vs. } t \text{ plot}$$
$$= \tfrac{1}{2}(10)(15{,}000) + (20)(15{,}000) + \tfrac{1}{2}(20)(5000)$$
$$= 75{,}000 + 300{,}000 + 50{,}000 = 425{,}000 \text{ C}.$$

$$\textbf{[b]}\quad w = \int p\,dt = \int vi\,dt;$$

$$v = 250 \times 10^{-6}t + 10, \qquad 0 \leq t \leq 20 \text{ ks}.$$

$0 \leq t \leq 15{,}000s$:

$$i = 30 - 666.67 \times 10^{-6}t;$$

$$p = 300 + 833.33 \times 10^{-6}t - 166.67 \times 10^{-9}t^2;$$

$$w_1 = \int_0^{15{,}000} (300 + 833.33 \times 10^{-6}t - 166.67 \times 10^{-9}t^2)\,dt$$

$$= (4500 + 93.75 - 187.5)10^3 = 4406.25 \text{ kJ}.$$

$15{,}000 \text{ s} \leq t \leq 20{,}000 \text{ s}$:

$$i = 80 - 4 \times 10^{-3}t;$$

$$p = 800 - 20 \times 10^{-3}t - 10^{-6}t^2;$$

$$w_2 = \int_{15{,}000}^{20{,}000} (800 - 20 \times 10^{-3}t - 10^{-6}t^2)\,dt$$

$$= (4000 - 1750 - 1541.67)10^3 = 708.33 \text{ kJ};$$

$$w_T = w_1 + w_2 = 4406.25 + 08.33 = 5114.58 \text{ kJ}.$$

P 1.27 **[a]** q = area under i vs. t plot

$$= \frac{1}{2}(6)(5000) + (14)(5000) + \frac{1}{2}(6)(10{,}000) + (8)(10{,}000) + \frac{1}{2}(8)(5000)$$

$$= 15{,}000 + 70{,}000 + 30{,}000 + 80{,}000 + 20{,}000 = 215{,}000 \text{ C}.$$

$$\textbf{[b]}\quad w = \int p\,dt = \int vi\,dt;$$

$$v = 250 \times 10^{-6}t + 10, \qquad 0 \leq t \leq 20 \text{ ks}.$$

$0 \leq t \leq 5000s$:

$$i = 20 - 1.2 \times 10^{-3}t;$$

$$p = 200 - 7 \times 10^{-3}t - 0.3 \times 10^{-6}t^2;$$

$$w_1 = \int_0^{5000} (200 + 7 \times 10^{-3}t - 0.3 \times 10^{-6}t^2)\,dt$$

$$= 10^6 + 87{,}500 - 12{,}500 = 900 \text{ kJ}.$$

$5000 \text{ s} \leq t \leq 15{,}000 \text{ s}$:

$$i = 17 - 0.6 \times 10^{-3}t;$$

$$p = 170 - 1.75 \times 10^{-3}t - 0.15^{-6}t^2;$$

$$w_2 = \int_{5000}^{15{,}000} (170 - 1.75 \times 10^{-3}t - 0.15^{-6}t^2)\,dt$$

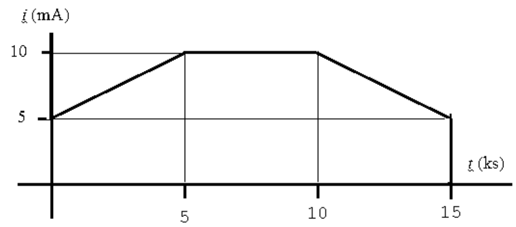
$$= 1.7 \times 10^6 - 175{,}000 - 162{,}500 = 1362.5 \text{ kJ};$$

15,000 s $\leq t \leq$ 20,000 s:

$$\begin{aligned}
i &= 32 - 1.6 \times 10^{-3}t; \\
p &= 320 - 8 \times 10^{-3}t - 0.4 \times 10^{-6}t^2; \\
w_3 &= \int_{15,000}^{20,000} (320 - 8 \times 10^{-3}t - 0.4 \times 10^{-6}t^2)\, dt \\
&= 1.6 \times 10^6 - 700,000 - 616,666.67 = 283.33 \text{ kJ};
\end{aligned}$$

$$w_T = w_1 + w_2 + w_3 = 900 + 1362.5 + 283.33 = 2545.83 \text{ kJ}.$$

P 1.28 [**a**]

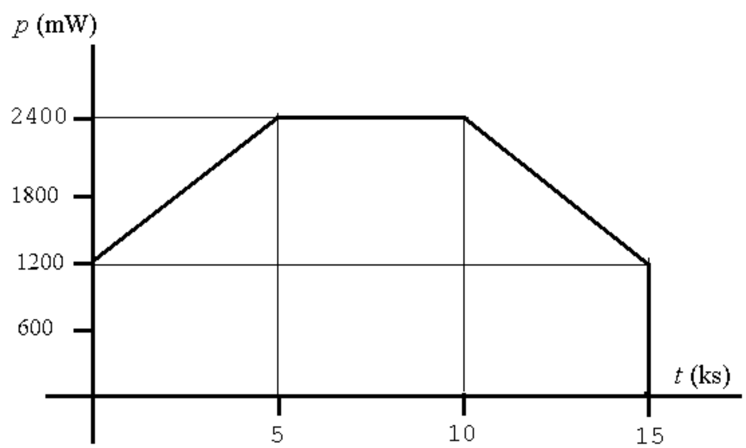


[**b**]

$$\begin{aligned}
i(t) &= 5 + 1 \times 10^{-3}t \text{ mA}, & 0 \leq t \leq 5 \text{ ks}; \\
i(t) &= 10 \text{ mA}, & 5 \text{ ks} \leq t \leq 10 \text{ ks}; \\
i(t) &= 20 - 1 \times 10^{-3}t \text{ mA}, & 10 \text{ ks} \leq t \leq 15 \text{ ks}; \\
i(t) &= 0, & t > 15 \text{ ks}.
\end{aligned}$$

$p = vi = 240i$ so

$$\begin{aligned}
p(t) &= 1200 + 0.24t \text{ mW}, & 0 \leq t \leq 5 \text{ ks}; \\
p(t) &= 2400 \text{ mW}, & 5 \text{ ks} \leq t \leq 10 \text{ ks}; \\
p(t) &= 4800 - 0.24t \text{ mW}, & 10 \text{ ks} \leq t \leq 15 \text{ ks}; \\
p(t) &= 0, & t > 15 \text{ ks}.
\end{aligned}$$



[**c**] To find the energy, calculate the area under the plot of the power:

$$w(5 \text{ ks}) = \frac{1}{2}(1.2)(5000) + (1.2)(5000) = 9 \text{ kJ};$$

$$w(10\text{ ks}) = w(5\text{ ks}) + (2.4)(5000) = 21\text{ kJ};$$

$$w(15\text{ ks}) = w(10\text{ ks}) + \frac{1}{2}(1.2)(5000) + (1.2)(5000) = 30\text{ kJ}.$$

P 1.29 **[a]** $0\text{ s} \le t < 10\text{ ms}$:

$v = 8\text{ V}$; $i = 25t\text{ A}$; $p = 200t\text{ W}$.

$10\text{ ms} < t \le 30\text{ ms}$:

$v = -8\text{ V}$; $i = 0.5 - 25t\text{ A}$; $p = 200t - 4\text{ W}$.

$30\text{ ms} \le t < 40\text{ ms}$:

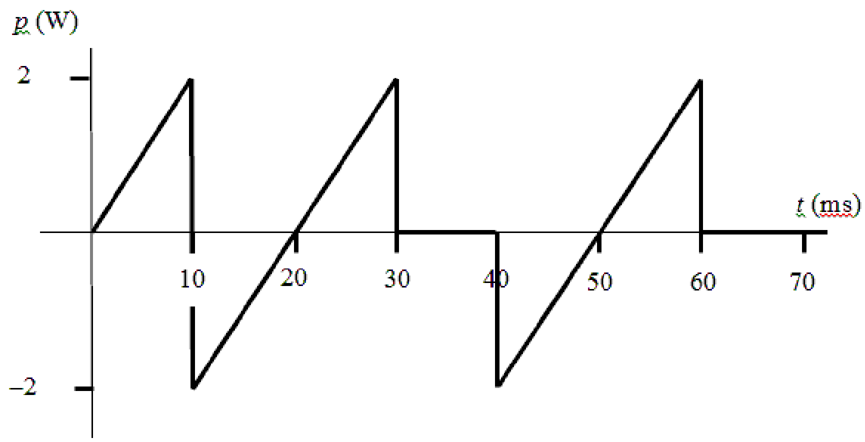
$v = 0\text{ V}$; $i = -250\text{ mA}$; $p = 0\text{ W}$.

$40\text{ ms} < t \le 60\text{ ms}$:

$v = 8\text{ V}$; $i = 25t - 1.25\text{ A}$; $p = 200t - 10\text{ W}$.

$t > 60\text{ ms}$:

$v = 0\text{ V}$; $i = 250\text{ mA}$; $p = 0\text{ W}$.



[b] Calculate the area under the curve from zero up to the desired time:

$$w(0.01) = \tfrac{1}{2}(2)(0.01) = 10\text{ mJ};$$

$$w(0.03) = w(0.01) - \tfrac{1}{2}(2)(0.01) + \tfrac{1}{2}(2)(0.01) = 10\text{ mJ};$$

$$w(0.08) = w(0.03) - \tfrac{1}{2}(2)(0.01) + \tfrac{1}{2}(2)(0.01) = 10\text{ mJ}.$$

P 1.30 $p_a = (-8)(7) = -56\text{ W}$;
$p_b = -(-2)(-7) = -14\text{ W}$;
$p_c = (10)(15) = 150\text{ W}$;
$p_d = -(10)(5) = -50\text{ W}$;
$p_e = (-6)(3) = -18\text{ W}$;
$p_f = (-4)(3) = -12\text{ W}$.
$\sum P_{\text{abs}} = 150\text{ W}$; $\sum P_{\text{del}} = 56 + 14 + 50 + 18 + 12 = 150\text{ W}$.

P 1.31
$$\begin{aligned}
p_{\rm a} &= v_{\rm a}i_{\rm a} = (6)(0.5) = 3 \text{ W};\\
p_{\rm b} &= -v_{\rm b}i_{\rm b} = -(10)(0.1) = -1 \text{ W};\\
p_{\rm c} &= -v_{\rm c}i_{\rm c} = -(-8)(-0.4) = -3.2 \text{ W};\\
p_{\rm d} &= -v_{\rm d}i_{\rm d} = -(-2)(0.3) = 0.6 \text{ W};\\
p_{\rm e} &= v_{\rm e}i_{\rm e} = (-2)(0.3) = -0.6 \text{ W};\\
p_{\rm f} &= -v_{\rm f}i_{\rm f} = -(4)(-0.2) = 0.8 \text{ W};\\
p_{\rm g} &= -v_{\rm g}i_{\rm g} = -(-6)(0.2) = 1.2 \text{ W};\\
p_{\rm h} &= v_{\rm h}i_{\rm h} = (2)(-0.4) = -0.8 \text{ W}.
\end{aligned}$$

Therefore,

$$\sum P_{\rm abs} = 3 + 0.6 + 0.8 + 1.2 = 5.6 \text{ W};$$

$$\sum P_{\rm del} = 1 + 3.2 + 0.6 + 0.8 = 5.6 \text{ W};$$

$$\sum P_{\rm abs} = \sum P_{\rm del}.$$

Thus, the interconnection satisfies the power check.

P 1.32
$$\begin{aligned}
p_{\rm a} &= v_{\rm a}i_{\rm a} = (-160)(-10) = 1600 \text{ W};\\
p_{\rm b} &= v_{\rm b}i_{\rm b} = (-100)(-20) = 2000 \text{ W};\\
p_{\rm c} &= -v_{\rm c}i_{\rm c} = -(-60)(6) = 360 \text{ W};\\
p_{\rm d} &= v_{\rm d}i_{\rm d} = (800)(-50) = -40{,}000 \text{ W};\\
p_{\rm e} &= -v_{\rm e}i_{\rm e} = -(800)(-20) = 16{,}000 \text{ W};\\
p_{\rm f} &= -v_{\rm f}i_{\rm f} = -(-700)(14) = 9800 \text{ W};\\
p_{\rm g} &= -v_{\rm g}i_{\rm g} = -(640)(-16) = 10{,}240 \text{ W}.
\end{aligned}$$

$\sum P_{\rm del} = 40{,}000$ W;
$\sum P_{\rm abs} = 1600 + 2000 + 360 + 16{,}000 + 9800 + 10{,}240 = 40{,}000$ W;
Therefore, $\sum P_{\rm del} = \sum P_{\rm abs} = 40{,}000$ W.

P 1.33 [**a**] If the power balances, the sum of the power values should be zero:

$$p_{\rm total} = -0.918 - 0.810 - 0.012 + 0.400 + 0.224 + 1.116 = 0.$$

Thus, the power balances.

[**b**] When the power is positive, the element is absorbing power. Since elements d, e, and f have positive power, these elements are absorbing power.

[c] The voltage can be calculated using $v = p/i$ or $v = -p/i$, with proper application of the passive sign convention:

$$v_\mathrm{a} = -p_\mathrm{a}/i_\mathrm{a} = -(-0.918)/(-0.051) = -18 \text{ V};$$
$$v_\mathrm{b} = p_\mathrm{b}/i_\mathrm{b} = (-0.81)/(0.045) = -18 \text{ V};$$
$$v_\mathrm{c} = p_\mathrm{c}/i_\mathrm{c} = (-0.012)/(-0.006) = 2 \text{ V};$$
$$v_\mathrm{d} = -p_\mathrm{d}/i_\mathrm{d} = -(0.4)/(-0.02) = 20 \text{ V};$$
$$v_\mathrm{e} = -p_\mathrm{e}/i_\mathrm{e} = -(0.224)/(-0.014) = 16 \text{ V};$$
$$v_\mathrm{f} = p_\mathrm{f}/i_\mathrm{f} = (1.116)/(0.031) = 36 \text{ V}.$$

P 1.34 **[a]** From the diagram and the table we have

$$p_\mathrm{a} = -v_\mathrm{a}i_\mathrm{a} = -(5000)(-0.150) = 750 \text{ W};$$
$$p_\mathrm{b} = v_\mathrm{b}i_\mathrm{b} = (2000)(0.250) = 500 \text{ W};$$
$$p_\mathrm{c} = -v_\mathrm{c}i_\mathrm{c} = -(3000)(0.200) = -600 \text{ W};$$
$$p_\mathrm{d} = v_\mathrm{d}i_\mathrm{d} = (-5000)(0.400) = -2000 \text{ W};$$
$$p_\mathrm{e} = -v_\mathrm{e}i_\mathrm{e} = -(1000)(-0.050) = 50 \text{ W};$$
$$p_\mathrm{f} = v_\mathrm{f}i_\mathrm{f} = (4000)(0.350) = 1400 \text{ W};$$
$$p_\mathrm{g} = -v_\mathrm{g}i_\mathrm{g} = -(-2000)(0.400) = 800 \text{ W};$$
$$p_\mathrm{h} = -v_\mathrm{h}i_\mathrm{h} = -(-6000)(-0.350) = -2100 \text{ W}.$$
$$\sum P_\mathrm{del} = 600 + 2000 + 2100 = 4700 \text{ W};$$
$$\sum P_\mathrm{abs} = 750 + 500 + 50 + 1400 + 800 = 3500 \text{ W}.$$

Therefore, $\sum P_\mathrm{del} \neq \sum P_\mathrm{abs}$ and the subordinate engineer is correct.

[b] The difference between the power delivered to the circuit and the power absorbed by the circuit is

$$-4700 + 3500 = 1200 \text{ W}.$$

One-half of this difference is 600 W, so it is likely that p_c is in error. Either the voltage or the current probably has the wrong sign. (In Chapter 2, we will discover that using KVL the voltage v_c should be -3.0 kV, not 3.0 kV!) If the sign of p_c is changed from negative to positive, we can recalculate the power delivered and the power absorbed as follows:

$$\sum P_\mathrm{del} = 2000 + 2100 = 4100 \text{ W};$$
$$\sum P_\mathrm{abs} = 750 + 500 + 600 + 50 + 1400 + 800 = 4100 \text{ W}.$$

Now the power delivered equals the power absorbed and the power balances for the circuit.

P 1.35 **[a]** We can add the powers supplied together and the powers absorbed together — if the power balances, these power sums should be equal:
$\sum P_{\rm sup} = 750 + 400 + 800 = 1950$ W;
$\sum P_{\rm abs} = 1600 + 150 + 200 = 1950$ W.
Thus, the power balances.

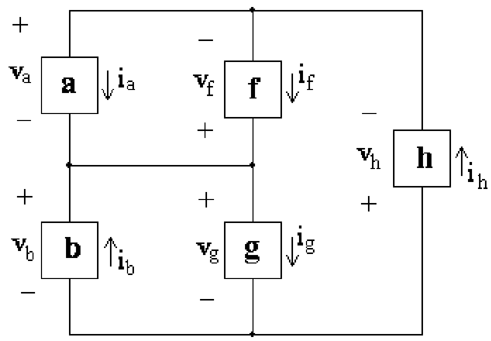
[b] The current can be calculated using $i = p/v$ or $i = -p/v$, with proper application of the passive sign convention. Remember that the power supplied is negative and the power absorbed is positive.

$$\begin{aligned}
i_{\rm a} &= -p_{\rm a}/v_{\rm a} = -(-750)/(-3000) = -250 \text{ mA};\\
i_{\rm b} &= -p_{\rm b}/v_{\rm b} = -(1600)/(4000) = -400 \text{ mA};\\
i_{\rm c} &= -p_{\rm c}/v_{\rm c} = -(-400)/(1000) = 400 \text{ mA};\\
i_{\rm d} &= p_{\rm d}/v_{\rm d} = (150)/(1000) = 150 \text{ mA};\\
i_{\rm e} &= p_{\rm e}/v_{\rm e} = (-800)/(-4000) = 200 \text{ mA};\\
i_{\rm f} &= p_{\rm f}/v_{\rm f} = (200)/(4000) = 50 \text{ mA};
\end{aligned}$$

P 1.36
$$\begin{aligned}
p_{\rm a} &= v_{\rm a}i_{\rm a} = (120)(-10) = -1200 \text{ W};\\
p_{\rm b} &= -v_{\rm b}i_{\rm b} = -(120)(9) = -1080 \text{ W};\\
p_{\rm c} &= v_{\rm c}i_{\rm c} = (10)(10) = 100 \text{ W};\\
p_{\rm d} &= -v_{\rm d}i_{\rm d} = -(10)(-1) = 10 \text{ W};\\
p_{\rm e} &= v_{\rm e}i_{\rm e} = (-10)(-9) = 90 \text{ W};\\
p_{\rm f} &= -v_{\rm f}i_{\rm f} = -(-100)(5) = 500 \text{ W};\\
p_{\rm g} &= v_{\rm g}i_{\rm g} = (120)(4) = 480 \text{ W};\\
p_{\rm h} &= v_{\rm h}i_{\rm h} = (-220)(-5) = 1100 \text{ W}.
\end{aligned}$$
$\sum P_{\rm del} = 1200 + 1080 = 2280$ W;
$\sum P_{\rm abs} = 100 + 10 + 90 + 500 + 480 + 1100 = 2280$ W.
Therefore, $\sum P_{\rm del} = \sum P_{\rm abs} = 2280$ W.

Thus, the interconnection now satisfies the power check.

P 1.37 **[a]** The revised circuit model is shown below:



[b] The expression for the total power in this circuit is

$$v_a i_a - v_b i_b - v_f i_f + v_g i_g + v_h i_h$$

$$= (120)(-8) - (120)(8) - (-120)(6) + (120)(6) + (-240)i_h = 0.$$

Therefore,

$$240 i_h = -960 - 960 + 720 + 720 = -480$$

so

$$i_h = \frac{-480}{240} = -2 \text{ A}.$$

Thus, if the power in the modified circuit is balanced the current in component h is -2 A.