In this example, the survey crew moves around the four sides of a square, so there are two measurements in the x-direction and two measurements in the y-direction. If the errors E_1 and E_2 are known for two measurements, x_1 and x_2, the error associated with the sum or difference $x_1 \pm x_2$ is

$$E\{x_1 \pm x_2\} = \sqrt{E_1^2 + E_2^2}$$

In this case, the error in the x-direction is

$$\begin{aligned} E_x &= \sqrt{(0.1422)^2 + (0.1422)^2} \\ &= 0.2011 \end{aligned}$$

The error in the y-direction is calculated the same way and is also 0.2011. E_x and E_y are combined by the Pythagorean theorem to yield

$$\begin{aligned} E_{\text{closure}} &= \sqrt{(0.2011)^2 + (0.2011)^2} \\ &= \boxed{0.2844 \quad (0.28)} \end{aligned}$$

The answer is (C).

(g) In surveying, error may be expressed as a fraction of one or more legs of the traverse. Assume that the total of all four legs is to be used as the basis.

$$E = \frac{E_{\text{closure}}}{\sum_i x_i} = \frac{0.2844}{(4)(1249)} = \boxed{\frac{1}{17{,}567} \quad (1{:}17{,}600)}$$

The answer is (A).

(h) In surveying, a class 1 third-order error is smaller than 1/10,000. The error of 1/17,567 is smaller than the third-order error; therefore, the error is within the third-order accuracy.

The answer is (C).

(i) An experiment is accurate if it is unchanged by experimental error. Precision is concerned with the repeatability of the experimental results. If an experiment is repeated with identical results, the experiment is said to be precise. However, it is possible to have a highly precise experiment with a large bias.

The answer is (D).

(j) A systematic error is one that is always present and is unchanged from sample to sample. For example, a steel tape that is 0.02 ft short introduces a systematic error.

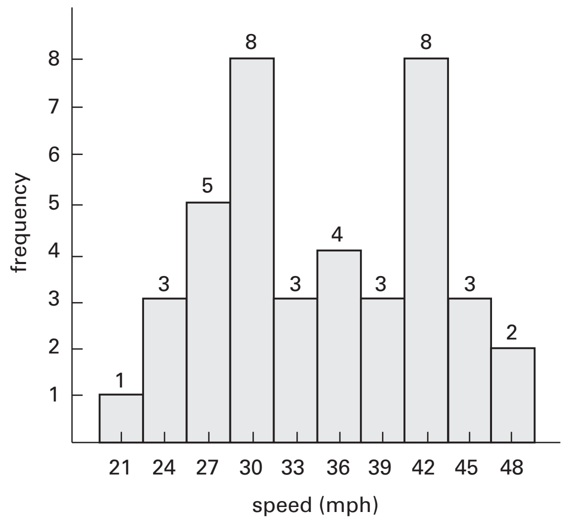
The answer is (B).

6. For (a) ~~and (d),~~ tabulate the frequency distribution data.

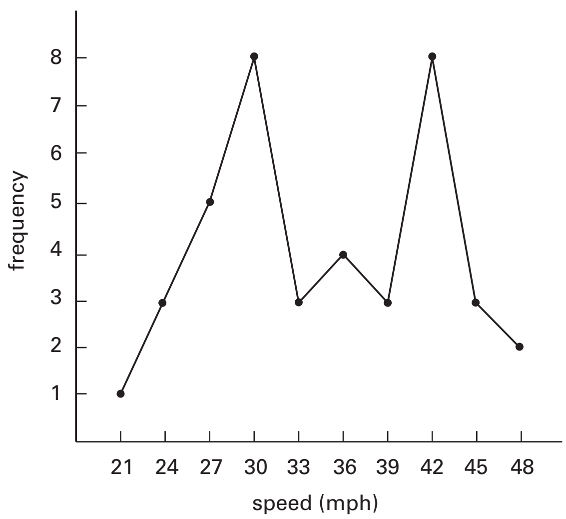
(The lowest speed is 20 mph and the highest speed is 48 mph; therefore, the range is 28 mph. Choose 10 cells with a width of 3 mph.)

midpoint	interval (mph)	frequency	cumulative frequency	cumulative percent
21	20–22	1	1	3
24	23–25	3	4	10
27	26–28	5	9	23
30	29–31	8	17	43
33	32–34	3	20	50
36	35–37	4	24	60
39	38–40	3	27	68
42	41–43	8	35	88
45	44–46	3	38	95
48	47–49	2	40	100

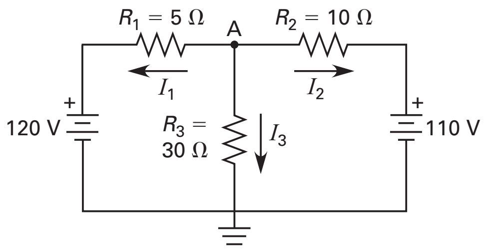
(b)



(c)



5. Consider the following circuit.



The principal node A is labeled. The node at the lower portion of the circuit is chosen as the reference or ground node. All currents are assumed to be positive.

Writing KCL for node A gives

$$\frac{V_A - 120\ \text{V}}{R_1} + \frac{V_A - 0\ \text{V}}{R_3} + \frac{V_A - 110\ \text{V}}{R_2} = 0$$

Solve for V_A.

$$\frac{V_A}{R_1} - \frac{120\ \text{V}}{R_1} + \frac{V_A}{R_3} + \frac{V_A}{R_2} - \frac{110\ \text{V}}{R_2} = 0$$

$$\begin{aligned}
\frac{V_A}{R_1} + \frac{V_A}{R_3} + \frac{V_A}{R_2} &= \frac{120\ \text{V}}{R_1} + \frac{110\ \text{V}}{R_2} \\
V_A &= \frac{\dfrac{120\ \text{V}}{R_1} + \dfrac{110\ \text{V}}{R_2}}{\dfrac{1}{R_1} + \dfrac{1}{R_3} + \dfrac{1}{R_2}} \\
&= \frac{\dfrac{120\ \text{V}}{5\ \Omega} + \dfrac{110\ \text{V}}{10\ \Omega}}{\dfrac{1}{5\ \Omega} + \dfrac{1}{30\ \Omega} + \dfrac{1}{10\ \Omega}} \\
&= 105\ \text{V}
\end{aligned}$$

Use V_A to determine the desired current.

$$I_3 = \frac{V_A}{R_3} = \frac{105\ \text{V}}{30\ \Omega} = \boxed{3.5\ \text{A}}$$

6. The resistance of the wire is calculated from Eq. 26.1.

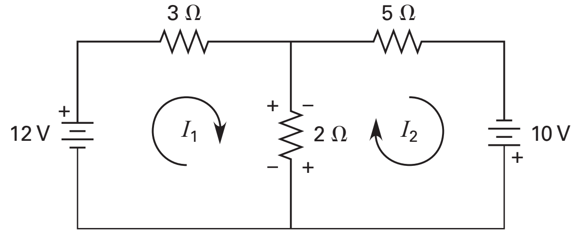
$$\begin{aligned}
R &= \frac{\rho l}{A} = \frac{\rho l}{\pi\left(\dfrac{d}{2}\right)^2} \\
&= \frac{(1.72 \times 10^{-8}\ \Omega\cdot\text{m})(150\ \text{m})}{\pi\left(\dfrac{0.5 \times 10^{-3}\ \text{m}}{2}\right)^2} \\
&= 13.14\ \Omega
\end{aligned}$$

From Eq. 26.11, Ohm's law, the voltage drop is

$$\begin{aligned}
V &= IR \\
&= (15\ \text{A})(13.14\ \Omega) \\
&= \boxed{197.10\ \text{V} \quad (200\ \text{V})}
\end{aligned}$$

The answer is (D).

7. Apply Kirchhoff's voltage law (KVL) around each loop as shown.



KVL for loop 1 is

$$12\ \text{V} - I_1 R_{3\ \Omega} - I_1 R_{2\ \Omega} + I_2 R_{2\ \Omega} = 0$$

Rearranging the equation for KVL for loop 1 gives

$$\begin{aligned}
12\ \text{V} &= I_1(R_{2\ \Omega} + R_{3\ \Omega}) + I_2 R_{2\ \Omega} \\
12\ \text{V} &= I_1(5\ \Omega) + I_2(2\ \Omega)
\end{aligned}$$

KVL for loop 2 is

$$10\ \text{V} - I_2 R_{2\ \Omega} + I_1 R_{2\ \Omega} - I_2 R_{5\ \Omega} = 0$$

Rearranging the equation for KVL for loop 2 gives

$$\begin{aligned}
10\ \text{V} &= I_1 R_{2\ \Omega} + I_2(R_{2\ \Omega} + R_{5\ \Omega}) \\
10\ \text{V} &= I_1(2\ \Omega) + I_2(7\ \Omega)
\end{aligned}$$

Replace equal signs with minus signs

For loop 1, from Cramer's rule and matrix algebra, the current is

$$\begin{aligned}
I_1 = \frac{|\mathbf{A_1}|}{|\mathbf{A}|} &= \frac{\begin{vmatrix} 12\ \text{V} & 2\ \Omega \\ 10\ \text{V} & 7\ \Omega \end{vmatrix}}{\begin{vmatrix} 5\ \Omega & -2\ \Omega \\ -2\ \Omega & 7\ \Omega \end{vmatrix}} \\
&= \frac{(12\ \text{V})(7\ \Omega) - (10\ \text{V})(-2\ \Omega)}{(5\ \Omega)(7\ \Omega) - (-2\ \Omega)(-2\ \Omega)} \\
&= 3.354\ \text{A}
\end{aligned}$$

For loop 2, from Cramer's rule and matrix algebra, the current is

$$
\begin{aligned}
I_2 = \frac{|\mathbf{A}_2|}{|\mathbf{A}|} &= \frac{\begin{vmatrix} 5\ \Omega & 12\ \text{V} \\ 2\ \Omega & 10\ \text{V} \end{vmatrix}}{\begin{vmatrix} 5\ \Omega & 2\ \Omega \\ 2\ \Omega & 7\ \Omega \end{vmatrix}} \\
&= \frac{(5\ \Omega)(10\ \text{V}) - (-2\ \Omega)(12\ \text{V})}{(5\ \Omega)(7\ \Omega) - (-2\ \Omega)(-2\ \Omega)} \\
&= 2.387\ \text{A}
\end{aligned}
$$

Replace highlighted '2's with -2

The actual current through the 2 Ω resistor is the combination of the two currents, using the directions assumed. The sign of the result determines the correct direction of the current.

$$
\begin{aligned}
I_{2\Omega} &= I_1 - I_2 \\
&= \cancel{2.06\ \text{A} - 0.84\ \text{A}} \\
&= \cancel{1.22\ \text{A}}
\end{aligned}
$$

= 3.354A - 2.387A
= 0.967A

From Eq. 26.13, the power dissipated in the 2 Ω resistor is

$$
\begin{aligned}
P &= I^2R = I_{2\Omega}^2 R_{2\Omega} \\
&= (\cancel{1.22}\ \text{A})^2(2\ \Omega) \\
&= \boxed{\cancel{2.97\ \text{W}} \quad \cancel{(3\ \text{W})}}
\end{aligned}
$$

0.967

1.87 W (2W)

The answer is (B).

8. The average power usage for the weekend is

$$
\begin{aligned}
P &= \frac{P_t}{N_{\text{days}}} \\
&= \frac{12\ \text{MW} + 13\ \text{MW} + 11\ \text{MW}}{3} \\
&= 12\ \text{MW}
\end{aligned}
$$

From Eq. 26.14, the decibel level is

$$
\begin{aligned}
\text{ratio (in dB)} &= 10\log_{10}\frac{P}{P_0} \\
&= 10\log_{10}\frac{12\times 10^6\ \text{W}}{1\times 10^3\ \text{W}} \\
&= \boxed{40.79\ \text{W} \quad (41\ \text{dB})}
\end{aligned}
$$

The answer is (C).

9. The voltage regulation is given by Eq. 26.15.

$$
\text{VR} = \frac{V_{\text{nl}} - V_{\text{fl}}}{V_{\text{fl}}} \times 100\%
$$

Equation 26.15 is rearranged in order to find the generator's full load voltage.

$$
\begin{aligned}
V_{\text{fl}} &= \frac{V_{\text{nl}}}{\frac{\text{VR}}{100\%} + 1} = \frac{250\ \text{V}}{\frac{3\%}{100\%} + 1} \\
&= \boxed{242.7\ \text{V} \quad (240\ \text{V})}
\end{aligned}
$$

The answer is (B).

10. Use Millman's theorem. The two voltage sources in parallel, V_1 and V_2, can be combined into a single voltage source of 12 V. This 12 V source is in series with V_3. The resistor does not have an impact until the current flows (i.e., until a load is added). Sum the voltages to find the total voltage in the circuit.

$$
\begin{aligned}
V_t &= V_{1,2} + V_3 \\
&= 12\ \text{V} + 3\ \text{V} \\
&= \boxed{15\ \text{V}}
\end{aligned}
$$

The answer is (C).

11. The two circuits are equivalent if the voltages at the terminals and the resistance as seen from the terminals are identical in each circuit.

Determine the source current by shorting terminals A and B and applying Ohm's law, Eq. 26.11.

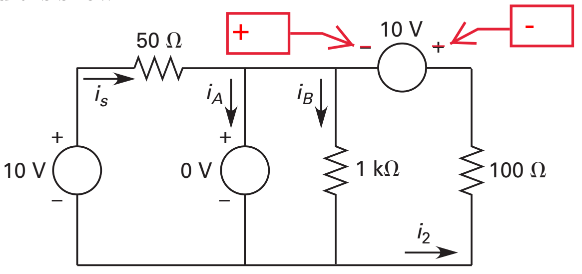
$$
\begin{aligned}
V_s &= I_s R_{\text{int}} \\
I_s &= \frac{V_s}{R_{\text{int}}} \\
&= \frac{4\ \text{V}}{0.75\ \Omega} \\
&= \boxed{5.33\ \text{A} \quad (5.3\ \text{A})}
\end{aligned}
$$

The resistance is found from Ohm's law. The voltage across R_I must be 4 V.

$$
\begin{aligned}
V_{\text{AB}} &= V_{\text{terminal}} = V_s \\
&= I_s R_I \\
R_I &= \frac{V_s}{I_s} = \frac{4\ \text{V}}{5.33\ \text{A}} \\
&= \boxed{0.75\ \Omega}
\end{aligned}
$$

The answer is (A).

18. With the switch open for a long time, the upper-right capacitor is charged to 10 V and the lower (center) capacitor is discharged to 0 V. At the instant of switching, the capacitors can be modeled as ideal voltage sources with their initial voltages. The resulting equivalent circuit is shown.



KVL on the left loop is

$$10\ \text{V} - (50\ \Omega)i_s + 0.0 = 0$$
$$i_s = 1/5\ \text{A}$$

KVL on the right loop is

$$0.0 + 10\ \text{V} - (100\ \Omega)i_2 = 0$$
$$i_2 = 1/10\ \text{A}$$

The current in the right (upper) capacitor is i_2, with 0.1 A flowing left.

As the voltage across the 1 kΩ resistor is zero, $i_B = 0$ A. By KCL, the other capacitor current is

$$i_A = i_s + i_2 = \tfrac{1}{5}\ \text{A} + \tfrac{1}{10}\ \text{A} = \boxed{0.3\ \text{A}}$$

19. The homogeneous equation is

$$s^2 + 4s + 4 = 0$$

The roots are $(s+2)^2$. The homogeneous solution is

$$Ae^{-2t} + Bte^{-2t}$$

The steady-state solution is

$$\begin{aligned} s &\rightarrow j\omega \\ \omega &= 4 \\ \frac{d}{dt} &\rightarrow j\omega \\ \frac{d^2}{dt^2} &\rightarrow -\omega^2 = -16 \end{aligned}$$

The sine reference is used.

$$\begin{aligned} 20\ \text{V} &= (-16\ \Omega + 16j\ \Omega + 4\ \Omega)I_{ss} \\ I_{ss} &= \frac{20}{-12 + j16} = -0.6 + j(-0.8)\ \text{A} \\ i_{ss} &= -0.6\sin 4t - 0.8\sin(4t + 90°)\ \text{A} \\ &= -0.6\sin 4t - 0.8\cos 4t\ \text{A} \\ i &= i_{ss} + Ae^{-2t} + Bte^{-2t} \\ i(0) &= -0.8\ \text{A} + A = 0 \\ A &= 0.8\ \text{A} \\ \frac{di}{dt} &= -2.4\cos 4t + 3.2\sin 4t \\ &\quad -2Ae^{-2t} + Be^{-2t} - 2Bte^{-2t} \\ \frac{di}{dt}(0) &= -2.4 - 2A + B = 4\ \text{A} \\ B &= 2.4 + 2A + 4 = 8\ \text{A} \\ i(t) &= 0.8e^{-2t} + 8te^{-2t} - 0.6\sin 4t - 0.8\cos 4t\ \text{A} \\ &= \boxed{0.8e^{-2t} + 8te^{-2t} - \sin(4t + 53.1°)\ \text{A}} \end{aligned}$$

20. The initial charge on the 1 μF capacitor is

$$\begin{aligned} Q_{1,\text{initial}} &= CV_0 \\ &= (10^{-6}\ \text{F})(100\ \text{V}) \\ &= 10^{-4}\ \text{C} \end{aligned}$$

The initial energy, $W_{1,\text{initial}}$, is

(a)

$$\begin{aligned} W_{1,\text{initial}} &= \tfrac{1}{2}C_1V_0^2 \\ &= \left(\frac{1}{2}\right)(10^{-6}\ \text{F})(100\ \text{V})^2 \\ &= 0.005\ \text{J} \quad (5\ \text{mJ}) \end{aligned}$$

In the final condition, the voltage across the two capacitors is the same.

$$\begin{aligned} W_{2,\text{initial}} &= 0 \\ V_f &= \frac{Q_1}{C_1} = \frac{Q_2}{C_2} \\ Q_2 &= 2Q_1 \end{aligned}$$

SOLUTIONS

1. Core losses include those caused by eddy currents and hysteresis. In the exact transformer model, these are accounted for by $G_c = 1/R_c$.

The answer is (B).

2. Magnetic flux leakage is a term used to describe any flux that is not mutual. The primary and secondary self-inductances represented by X_p and X_s are not mutual.

The answer is (D).

3. The eddy current loss is found from

$$P_e = k_e B_m^2 f^2 m$$

Assume 60 Hz is the frequency. Substitute the given values.

$$\begin{aligned} P_e &= (4 \times 10^{-4})(1.4\ \text{T})^2(60\ \text{Hz})^2(200\ \text{kg}) \\ &= \boxed{565\ \text{W} \quad (570\ \text{W})} \end{aligned}$$

The answer is (D).

4. The voltage regulation is

$$\begin{aligned} \text{VR} &= \frac{V_{\text{nl}} - V_{\text{fl}}}{V_{\text{fl}}} \\ &= \frac{\frac{V_p}{a} - V_{s,\text{rated}}}{V_{s,\text{rated}}} \end{aligned}$$

Because the voltage was measured at the output of the secondary, it is equivalent to V_p/a. Therefore, the voltage regulation is

$$\begin{aligned} \text{VR} &= \frac{35.02\ \text{kV} - 34.5\ \text{kV}}{34.5\ \text{kV}} \times 100\% \\ &= \boxed{1.5\%} \end{aligned}$$

The answer is (C).

5. The open-circuit test determines the parameters associated with core losses. The apparent power is

$$\begin{aligned} S_{\text{oc}} &= I_{1\text{oc}} V_{1\text{oc}} \\ &= (0.25\ \text{A})(120\ \text{V}) \\ &= \boxed{30\ \text{VA}} \end{aligned}$$

The answer is (B).

6. The open-circuit test obtains the core parameters G and B.

$$G = \frac{P_{\text{oc}}}{V_{\text{oc}}^2} = \frac{900\ \text{W}}{(13{,}800\ \text{V})^2} = \boxed{4.73 \times 10^{-6}\ \text{S}}$$

$$Q^2 = S^2 - P^2 = \big((13{,}800\ \cancel{\text{VA}})(0.2\ \text{A})\big)^2 - (900\ \text{W})^2$$

V

$$Q = 2609\ \text{VAR}$$

$$B = \frac{Q}{V^2} = \frac{2609\ \text{VAR}}{(13{,}800\ \text{V})^2} = \boxed{13.7 \times 10^{-6}\ \text{S}}$$

The turns ratio is

$$\begin{aligned} \frac{V_p}{N_p} &= \frac{V_s}{N_s} \\ \frac{N_p}{N_s} &= \frac{V_p}{V_s} = \frac{13{,}800\ \text{V}}{460\ \text{V}} \\ &= \boxed{30} \end{aligned}$$

7. (a)

$$\begin{aligned} N_p I_p &= N_s I_s \\ a &= \frac{N_p}{N_s} = \frac{I_s}{I_p} \\ &= \frac{100\ \text{A}}{20\ \text{A}} \\ &= 5 \\ P_{\text{sc}} &= I_p^2 R_p + I_s^2 R_s = 1000\ \text{W} \\ I_p^2(R_p + a^2 R_s) &= 1000\ \text{W} \\ R_p + a^2 R_s &= \frac{1000\ \text{W}}{(20\ \text{A})^2} = 2.5\ \Omega \end{aligned}$$

Assume $R_p = a^2 R_s = \boxed{1.25\ \Omega.}$

$$R_s = \frac{1.25\ \Omega}{(5)^2} = \boxed{0.05\ \Omega}$$

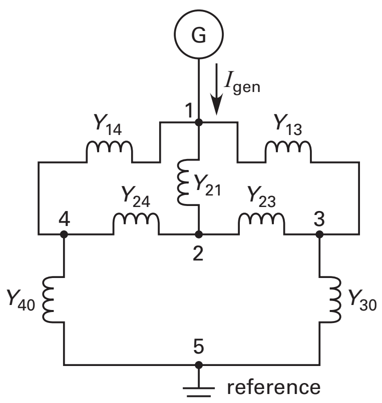
(b)

$$\begin{aligned} S &= V_p I_p = (80\ \text{V})(20\ \text{A}) = 1600\ \text{VA} \\ &= P + jQ \\ Q^2 &= S^2 - P^2 \\ Q &= 1249\ \text{VAR} \\ &= I_1^2(X_p + a^2 X_s) \\ X_p + a^2 X_s &= \frac{Q}{I_1^2} = \frac{1249\ \text{VAR}}{(20\ \text{A})^2} = 3.12\ \Omega \end{aligned}$$

40 Power System Analysis

PRACTICE PROBLEMS

1. Consider the following generation system with five nodes and five admittances. In order to use a power software analysis tool to model the distribution system attached to the generator, the equations for each node must be known and then placed in the bus admittance matrix. What is the nodal equation for node 2? How many nodal equations are required to determine all branch currents?



(A) $(V_1 - V_2)Y_{21} + (V_2 - V_3)Y_{23} + (V_4 - V_2)Y_{24} = 0$; 4 equations

(B) $(V_1 - V_2)Y_{21} + (V_2 - V_3)Y_{23} + (V_2 - V_4)Y_{24} = 0$; 5 equations

(C) $V_2(-Y_{21} + Y_{23} + Y_{24}) - V_1Y_{12} - V_3Y_{23} - V_4Y_{24} = 0$; 5 equations

(D) $V_2(Y_{21} + Y_{23} + Y_{24}) - V_1Y_{21} - V_3Y_{23} - V_4Y_{24} = 0$; 4 equations

2. What is most nearly the value of the apparent power, **S**, for a single phase circuit for which the voltage is 480 V$\angle 0°$ and the current is 30 A$\angle -37°$?

(A) 0.60 kVA$\angle 37°$

(B) 14 kVA$\angle 37°$

(C) 16 kVA$\angle -37°$

(D) 83 kVA$\angle -37°$

3. The line-to-line voltages of a balanced three-phase system are 120° apart but differ in magnitude and are 30° ahead of the line-to-neutral voltages. If the line-to-neutral voltages are considered to be of unit magnitude, what is the approximate magnitude of the line-to-line voltages, which are also 120° apart?

(A) 1.00 V

(B) 1.41 V

(C) 1.73 V

(D) 2.00 V

4. Which of the following statements regarding symmetrical components is NOT true?

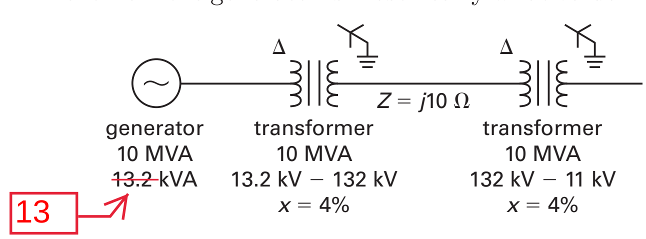
(A) A balanced system has phasor components of equal magnitude.

(B) The method of symmetrical components allows the calculation of unbalanced currents during fault conditions. The calculation uses three separate systems of components that are balanced and equal in magnitude.

(C) In a three-phase system, no zero-sequence line voltages exist except during imbalance or fault conditions.

(D) In delta-connected circuits, zero-sequence currents flow around the delta, and therefore do not affect the line currents.

5. Consider the three-phase transmission system shown. The transmission line current is 62.75 A. The load current from the generator is most nearly what value?



(A) 630 A

(B) 1100 A

(C) 6300 A

(D) 7200 A

6. A system's electrical parameters are

$$\begin{aligned}\mathbf{V} &= 480\ \text{V}\angle 0^\circ\\ \mathbf{I} &= 240\ \text{A}\angle -30^\circ\\ \text{THD} &= 2.5\%\end{aligned}$$

What is most nearly the apparent power, **S**?

VA (for all choices)

(A) $1.15 \times 10^3\ \cancel{\text{W}}\angle 30^\circ$

(B) $2.50 \times 10^3\ \cancel{\text{W}}\angle -30^\circ$

(C) $1.15 \times 10^5\ \cancel{\text{W}}\angle -30^\circ$

(D) $1.15 \times 10^5\ \cancel{\text{W}}\angle 30^\circ$

7. A balanced wye load has a measured voltage of $173.2\ \text{V}\angle 0^\circ$. The phase sequence is A-B-C. What is most nearly the voltage-to-neutral of phase B?

(A) $-150 + j86.6\ \text{V}$

(B) $-86.6 - j50\ \text{V}$

(C) $86.6 + j50\ \text{V}$

(D) $150 - j86.6\ \text{V}$

8. During phasor analysis using the operator a, the term $1 - a^2$ occurs. What is most nearly the value of this term in polar form?

(A) $1\ \angle -120^\circ$

(B) $1\ \angle 0^\circ$

(C) $1\ \angle 120^\circ$

(D) $\sqrt{3}\ \angle 30^\circ$

9. Three wye-connected generators supply a three-phase distribution system, with the majority of the loads delta-connected. The line voltage is 11 kV on all three generators. From the monitoring system, the data on the generators are

generator 1

1212 kVA, pf = 0.75 leading

generator 2

865 kVA, pf = 0.80 lagging

generator 3

1000 kVA, pf = 0.80 lagging

What is most nearly the total power supplied by the generators?

(A) 2.4 MW

(B) 3.1 MW

(C) 4.0 MW

(D) 6.4 MW

10. The terminal voltage at a wye-connected load is 12.5 kV line-to-line. The load is balanced with an impedance of $15\ \Omega\angle 30^\circ$. The distribution line impedance is $1.2\ \Omega\angle 80^\circ$. What is most nearly the line-to-line voltage of the substation that supplies this load through the distribution line?

(A) $7200\ \text{V}\angle 0^\circ$

(B) $7600\ \text{V}\angle 3^\circ$

(C) $7600\ \text{V}\angle 80^\circ$

(D) $13\,200\ \text{V}\angle 3^\circ$

4. A balanced system includes components of equal magnitude. Option A is true.

The method of symmetrical components was developed to simplify fault calculations. Fortescue's theorem proves three unbalanced phasors can be resolved in a system of three balanced phasors. Therefore, option B is true.

Because the voltages of a three-phase system always sum to zero, no zero-sequence voltages exist regardless of the imbalance. Option C is not true.

In delta-connected circuits, zero-sequence currents flow around the delta and do not impact the line currents. Therefore, option D is true.

The answer is (C).

5. The transmission line is downstream of the first transformer whose turns ratio is given by

$$n = \frac{13.2\ \text{kV}}{132\ \text{kV}} = 0.1$$

The relationship between the voltages and currents is

$$\frac{V_{\text{gen}}}{V_{\text{trans}}} = \frac{I_{\text{trans}}}{I_{\text{gen}}}$$

Solve for the current on the generator side.

$$I_{\text{gen}} = \left(\frac{V_{\text{trans}}}{V_{\text{gen}}}\right) I_{\text{trans}} = \frac{I_{\text{trans}}}{a}$$

$$\begin{aligned} I_{\text{gen}} &= \frac{I_{\text{trans}}}{n} = \frac{62.75\ \text{A}}{0.1} \\ &= \boxed{627.5\ \text{A} \quad (630\ \text{A})} \end{aligned}$$

The answer is (A).

6. The apparent power, **S**, is given by

$$\mathbf{S} = \mathbf{VI}^*$$

The current is

$$\begin{aligned} \mathbf{I} &= 240\ \text{A}\angle{-30^\circ} \\ &= 208 - j120\ \text{A} \end{aligned}$$

The complex conjugate of the current is

$$\begin{aligned} \mathbf{I}^* &= 208 + j120\ \text{A} \\ &= 240\ \text{A}\angle 30^\circ \end{aligned}$$

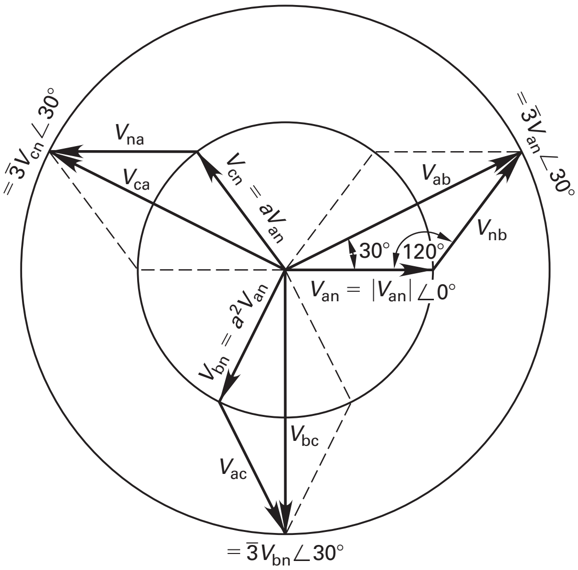
The apparent power, **S**, is calculated as

$$\begin{aligned} \mathbf{S} &= \mathbf{VI}^* \\ &= (480\ \text{V}\angle 0^\circ)(240\ \text{A}\angle 30^\circ) \\ &= \boxed{1.15 \times 10^5\ \cancel{\text{W}}\angle 30^\circ} \end{aligned}$$

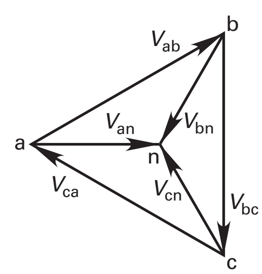
VA

The answer is (D).

7. Balanced wye voltage relationships are shown.



(a) line-to-line versus line-to-neutral voltages



(b) alternative line-to-line versus line-to-neutral voltages

Calculate the voltage-to-neutral of phase A.

$$\begin{aligned} V_{\text{ab}} &= \sqrt{3}\, V_{\text{an}}\angle 30^\circ \\ V_{\text{an}} &= \frac{V_{\text{ab}}}{\sqrt{3}}\angle{-30^\circ} \\ &= \frac{173.2\ \text{V}}{\sqrt{3}}\angle{-30^\circ} \\ &= 100\ \text{V}\angle{-30^\circ} \end{aligned}$$

System Analysis

13. ~~An arc flash hazard analysis is NOT required if a circuit is rated for~~

~~(A) 240 V or less and is supplied by one transformer that is rated for less than 125 kVA~~

~~(B) 600 V or less and is supplied by one transformer that is rated for less than 125 kVA~~

~~(C) 600 V or less and is supplied by one transformer that is rated for less than 500 kVA~~

~~(D) 1000 V or less and is supplied by one transformer that is rated for less than 500 kVA~~

13. A sustainable arc is possible, but less likely, in three-phase systems when the circuit is rated for the following.

(A) 240 V or less with available short circuit current below 2000 A
(B) 600 V or less supplied by one transformer that is rated for less than 125 kVA
(C) 600 V or less supplied with available short circuit current below 2000 A
(D) 1000 V or less supplied by one transformer that is rated for less than 125 kVA

14. Which of the following should be used to determine the arc flash incident energy and boundaries for voltages above 15 kV?

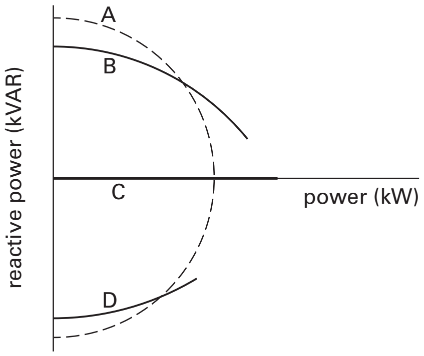
(A) IEEE C2, *National Electrical Safety Code*

(B) a paper or article by R. L. Doughty and/or T. E. Neal

(C) IEEE Standard 1584

(D) a paper or article by Ralph Lee

15. Consider the generator capability shown.



To set the protection setting for the generator correctly, the capability curves must be analyzed and limits set within their boundaries. Which curve or line indicates the rotor current limit?

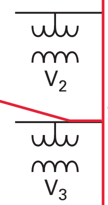
(A) curve A

(B) curve B

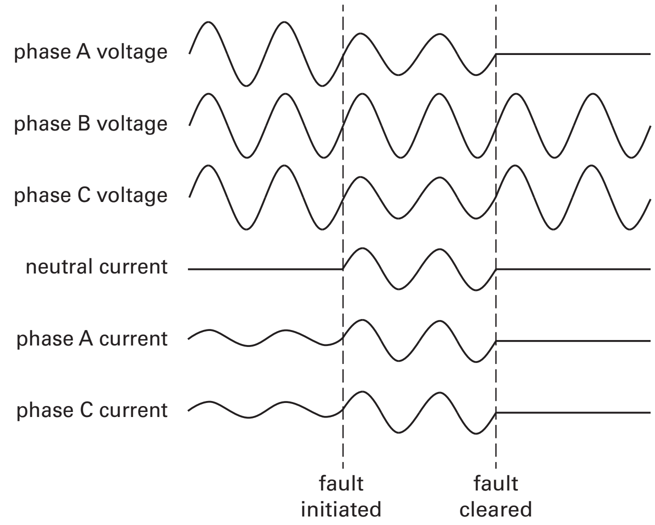
(C) line C

(D) curve D

16. Consi... setup for a...



Since volta... a different... ignated ph... toring ph... monitored... these inpu... recordings of the signal traces. One such recording shows



For the event recorded, which fault has occurred?

(A) phase A to phase C to ground

(B) phase A to phase B to ground

(C) phase B to phase C to ground

(D) phase to ground

17. A red lamp on a breaker generally indicates

(A) a breaker fault

(B) an open breaker

(C) a closed breaker

(D) a breaker that requires maintenance

Protection and Safety

10. A distance relay, also called an impedance or ratio relay, is bidirectional and operates on faults within a given distance from the relay.

A differential relay operates on a difference in currents from two separate sensing points and only responds to faults between those points. A directional relay operates on faults to either the left or the right of its location in a distribution system. A phase angle relay compares the angle between the current and the voltage to determine the direction of power flow. When the power flow is abnormal, the relay sends a protective signal.

The answer is (C).

11. A large motor is defined as 37 kW, which is 50 hp or larger per *IEEE Guide for Performing Arc-Flash Hazard Calculations* (IEEE Std 1584).

The answer is (D).

12. From NEC Art. 240.87, when an instantaneous trip circuit breaker is not available, equivalent means are approved: (a) zone-selective interlocking, (b) differential relaying, and (c) energy-reducing maintenance switching with a local status indicator that is used when a worker is within the arc flash boundary defined by NFPA 70E, *Standard for Electrical Safety in the Workplace*.

The answer is (B).

13. ~~From NFPA 70E, *Standard for Electrical Safety in the Workplace*, Art. 130, Exception no. 2, an arc flash hazard analysis is not required when a circuit is rated for 240 V or less and is supplied by a single transformer that is rated less than 125 kVA.~~

The answer is (A).

14. All the answer options can be used to calculate arc flash incident energy and appropriate boundaries. Their assumptions and limitations are summarized in Annex D of NFPA 70E, *Standard for Electrical Safety in the Workplace*.

IEEE C2, *National Electrical Safety Code* is the source for information on high-voltage lines from 15 kV to 500 kV.

The answer is (A).

15. Curve B is the armature current limit. Line C is the true power line, where the power factor is equal to one, pf = 1. Curve D is the end ring limit, also known as the underexcitation limit.

The generator must operate within the limits of curves A, B, and D.

Curve A is the rotor current limit, also known as the overexcitation limit, and represents the maximum limit of the rotor current before heating effects become detrimental.

The answer is (A).

16. The recording, known as an oscillogram, shows an impact to phase A and phase C voltage. The fault includes those two phases. In addition, neutral current changed from 0 A before the fault to a given value. The fault occurred from phase A to phase C to ground.

The answer is (A).

17. Red is the industry-standard indication that a breaker is in service, or closed. Red, meaning "stop," indicates that the breaker is not safe for human interaction or maintenance. Because the breaker is closed, voltage or current is present.

The answer is (C).

18. COMTRADE is an IEEE standard for the data files of protection systems. ETAP and SKM are power system analysis tools. Modbus is a communication protocol. Synchrophasor is an IEEE standard for the output files of phasor measurement units (PMUs), whose

13. NFPA 70E, Standard for Electrical Safety in the Workplace, previous editions indicated no need for an arc flash hazard analysis for systems 240 V and less as long as the supplying transformer was rated for 125 kVA or less. In the 2018 update, this requirement is completely gone and a reference is made in Table 130.5(C) Informational Note #6 to refer to IEEE 1584, Guide for Performing Arc Flash Calculations, for more information. Nevertheless, example calculations remain in NFPA 70E Annex D.

IEEE 1584, which previously had nearly matched NFPA 70E regarding 240 V three-phase circuits, in 2018 was updated to, " A sustainable arc is possible, but less likely, in three-phase systems when the circuit is rated for 240 V or less with available short circuit current below 2000 A."
The answer is (A)

$$= 22 + j16.5\ \Omega$$

Protection and Safety

Because of rounding, the powers are recalculated and the remainder are assigned to rotational losses.

$$\begin{aligned} P_{\text{rotational losses}} &= P_{\text{loss}} - \frac{V_a^2}{R_f} - R_a I_a^2 \\ &= 1607\ \text{W} - \frac{(120\ \text{V})^2}{26.9\ \Omega} \\ &\quad -(0.173\ \Omega)(55.54\ \text{A})^2 \\ &= 538\ \text{W} \end{aligned}$$

The air-gap power must then be

$$\begin{aligned} P_{\text{air gap}} &= P_{\text{out}} + P_{\text{rotational losses}} \\ &= 5.593n + 538\ \text{W} \end{aligned}$$

The air-gap power is also $E_g I_a$, and E_g is proportional to I_f and n.

$$E_g = k' I_f n = k''\left(\frac{n}{R_f}\right)$$

At $n = 1000$ rpm and $R_f = 26.9\ \Omega$,

$$\begin{aligned} E_g &= 120\ \text{V} - (55.54\ \text{A})(0.173\ \Omega) \\ &= 110.4\ \text{V} \\ k'' &= \frac{(110.4\ \text{V})(26.9\ \Omega)}{1000\ \frac{\text{rev}}{\text{min}}} \\ &= 2.97\ \frac{\text{V}\cdot\Omega}{\frac{\text{rev}}{\text{min}}} \\ E_g &= 2.97\left(\frac{n}{R_f}\right) \\ I_a &= \frac{120\ \text{V} - E_g}{R_a} \\ &= \frac{120\ \text{V} - (2.97)\left(\frac{n}{R_f}\right)}{0.173\ \Omega} \\ &= 694\ \text{A} - (17.2)\left(\frac{n}{R_f}\right) \\ P_{\text{air gap}} &= E_g I_a \\ &= (2061)\left(\frac{n}{R_f}\right) - (51.08)\left(\frac{n}{R_f}\right)^2 \end{aligned}$$

Equating the electrical side to the mechanical side,

$$(51.08)\left(\frac{n}{R_f}\right)^2 + \left(5.593 - \frac{2061}{R_f}\right)n + 538\ \text{W} = 0$$

$$0 = R_f^2 - \left(\frac{2061n}{5.593n + 538\ \text{W}}\right)(R_f) + \frac{51.08n^2}{5.593n + 538\ \text{W}}$$

(a) For $n = 1150$ rpm,

$$\begin{aligned} R_f^2 - (340.0\ \Omega)R_f + 9692\ \Omega^2 &= 0\ \Omega^2 \\ R_f &= \boxed{31.4\ \Omega} \end{aligned}$$

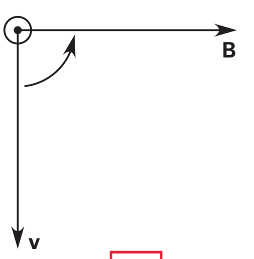
(b) For $n = 750$ rpm,

$$\begin{aligned} R_f^2 - (326.6\ \Omega)R_f + 6071\ \Omega^2 &= 0\ \Omega^2 \\ R_f &= \boxed{19.8\ \Omega} \end{aligned}$$

11. A series motor generates large torque at low speeds and overspeeds at low loads. The graph line that shows those properties is A.

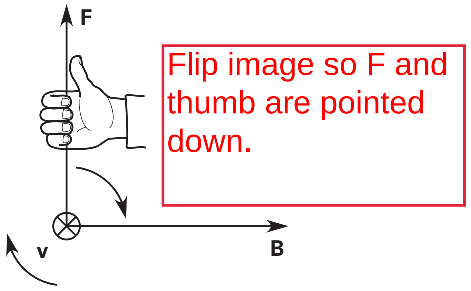
The answer is (A).

12. The $\mathbf{v} \times \mathbf{B}$ portion of the force equation (Eq. 43.9) or generated voltage equation (Eq. 43.4) is used to determine the direction. In this case, the velocity is the velocity of the conductor, which must be $\boxed{\text{down}}$ to provide the current out of the paper. This is shown by the head of the arrow. The right-hand rule is used to confirm.

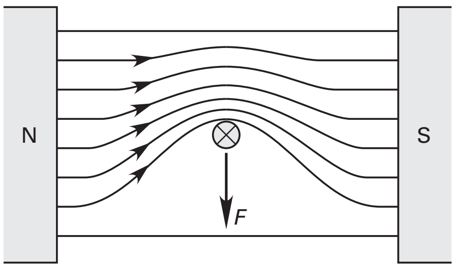


The answer is (~~A~~). C

13. The $\mathbf{v} \times \mathbf{B}$ portion of the force equation (Eq. 43.9) or generated voltage equation (Eq. 43.4) is used to determine the direction. In this case, the velocity is the velocity of the current flow. This is the direction of positive or conventional current flow, not the electron flow. Given that the velocity of the current is into the paper, and using the right-hand rule, the force is exerted downward.



The net result is shown.

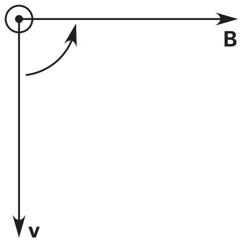


The answer is (A).

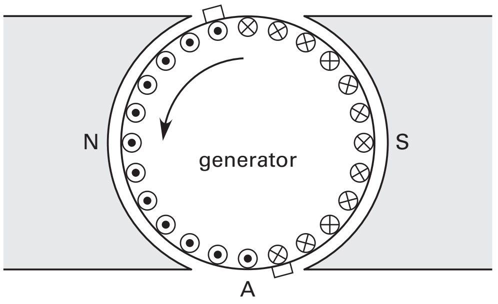
14. The $\mathbf{v} \times \mathbf{B}$ portion of the force equation (Eq. 43.9) or generated voltage equation (Eq. 43.4) is used to determine the direction.

The velocity of the current flow is used. This is the direction of positive or conventional current flow, not the electron flow. Using the right-hand rule, the force is upward, which means the direction is expected to be upward, resulting in clockwise rotation. However, the net force on the conductor is downward, resulting in counterclockwise rotation, indicating that the machine is operating as a generator. The force in question is the counterforce or countertorque.

The result can be confirmed using the velocity of the conductor itself. The velocity of the conductor is downward, resulting in a counterclockwise rotation with the magnetic field to the right, as shown. Using the right-hand rule, the current should flow out of the paper. The net force on the conductor results in conductor movement, such that it generates a voltage that results in a current out of the paper.

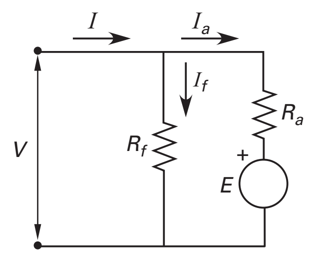


The machine is a generator.



The answer is (A).

15. The electrical portion of the circuit is shown.



Using Ohm's law, calculate the field current applied to the field.

$$\begin{aligned} V &= I_f R_f \\ I_f &= \frac{V}{R_f} \\ &= \frac{120 \text{ V}}{10 \ \Omega} \\ &= 12 \text{ A} \end{aligned}$$

Using Kirchhoff's current law (KCL) at the field/armature node, calculate the armature current.

$$\begin{aligned} I - I_f - I_a &= 0 \\ I_a &= I - I_f \\ &= 15 \text{ A} - 12\text{A} \\ &= 3\text{A} \end{aligned}$$

Substituting the armature current into the equation for Kirchhoff's voltage law (KVL) gives

$$\begin{aligned} V - I_a R_a - E_{\text{CEMF}} &= 0 \\ E_{\text{CEMF}} &= V - I_a R_a \\ &= 120 \text{ V} - (3 \text{ A})(0.1 \ \Omega) \\ &= 119.7 \text{ V} \quad (120 \text{ V}) \end{aligned}$$

The answer is (B).

10. At 25°C, a germanium diode shows a saturation current of 100 μA. What current is expected at 100°C, when the diode becomes "useless"?

11. At 25°C, a germanium diode shows a saturation current of 50 μA. What current is expected at 0°C?

12. At 25°C, a germanium diode shows a saturation current of 80 μA. At 25°C, what current is predicted for a voltage of −0.5 V?

13. The output of a single-phase transformer may be used in a switch-mode power supply in a three-phase, four-wire system to provide regulated output to modern low-power office equipment as well as lighting. Such a power supply generates which type of harmonics on the system?

(A) negative-sequence harmonics

(B) positive-sequence harmonics

(C) zero-sequence harmonics

(D) all of the above

14. A variable frequency drive (VFD) requires an electronic device to shape an incoming waveform so that only a portion of the power is passed to a downstream motor. Furthermore, the amount of the waveform passed must be controllable in order to vary the motor speed. Which electronic component is widely used in VFDs?

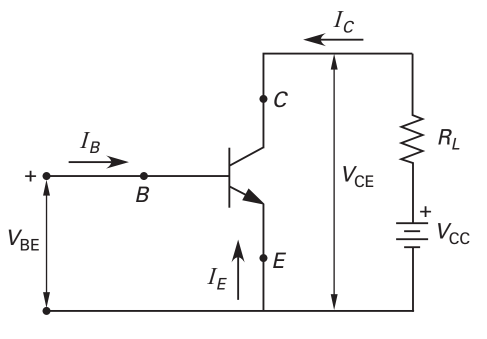
(A) insulated gate bipolar junction transistor (IGBT)

(B) Schottky diode

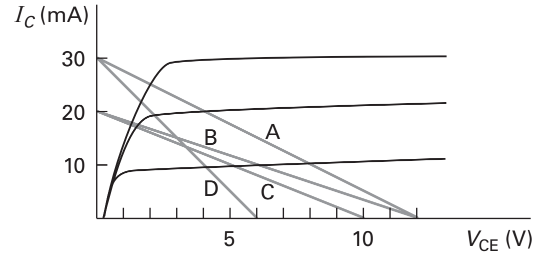
(C) silicon-controlled rectifier (SCR)

(D) either an IGBT or SCR

15. A common emitter (CE) circuit is shown.



The silicon bipolar junction transistor (BJT) used in the circuit has a collector supply voltage of 12 V. Which load line shown corresponds to the circuit?



(A) load line A

(B) load line B

(C) load line C

(D) load line D

SOLUTIONS

1. The two transistors are in a common emitter configuration, which is analogous to a common source configuration for field-effect transistors (FETs). This specific configuration is commonly referred to as a Darlington pair.

The answer is (D).

2. The Darlington pair has a high input resistance and a high current gain, h_{fe}. It is this forward current gain that enables the operation of the control relay.

The answer is (A).

3. The power in a single-phase motor is

$$\begin{aligned} P &= IV(\text{pf}) \\ &= (10\text{ A})(115\text{ V})(0.85) \\ &= \boxed{977.5\text{ W} \quad (980\text{ W})} \end{aligned}$$

The answer is (A).

4. Leakage current is minimized by using nonoscillatory power sources, such as DC-DC inverters and rechargeable batteries, or electrical items with ~~nonelectromagnetic~~ no electromagnetic coupling, such as motor generators. For biomedical devices, leakage current is set by IEC 60601–1 and is generally limited to 0.01–10 μA depending on the testing method, classification of applied parts, and whether under normal or single-fault conditions.

The answer is (D).

5. Radio frequency fields of sufficient intensity can damage human cells by depositing energy through heat.

The answer is (B).

The present worth of the alternate is zero when evaluated at its ROR.

$$0 = -\$150{,}000 + (\$17{,}524.40)(P/A,i\%,15)$$

Therefore,

$$(P/A,i\%,15) = \frac{\$150{,}000}{\$17{,}524.40} = 8.55949$$

Searching App. 58.B, this factor matches $i = 8\%$.

$$\boxed{\text{ROR} = 8.0\%}$$

The answer is (A).

14. (a) The conventional benefit/cost ratio is

$$B/C = \frac{B - D}{\cancel{D}} \longleftarrow \boxed{C}$$

The benefit/cost ratio will be

$$B/C = \frac{\$1{,}500{,}000 - \$300{,}000}{\$1{,}000{,}000} = \boxed{1.2}$$

The answer is (C).

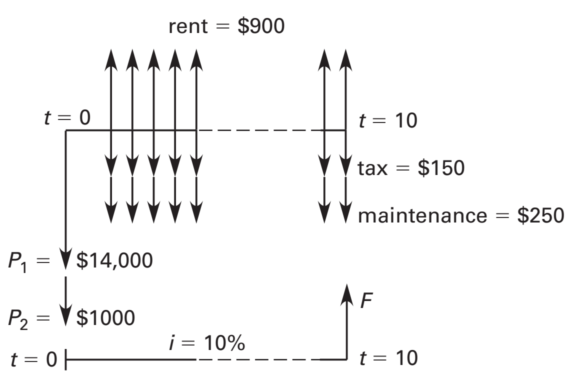
(b) The excess of benefits over cost is $\boxed{\$200{,}000.}$

The answer is (A).

15. The annual rent is

$$(\$75)\left(12 \frac{\text{months}}{\text{year}}\right) = \$900$$

$$\begin{aligned} P &= P_1 + P_2 = \$15{,}000 \\ A_1 &= -\$900 \\ A_2 &= \$250 + \$150 = \$400 \end{aligned}$$



Use App. 58.B.

$$\begin{aligned} F &= (\$15{,}000)(F/P,10\%,10) \\ &\quad +(\$400)(F/A,10\%,10) \\ &\quad -(\$900)(F/A,10\%,10) \end{aligned}$$

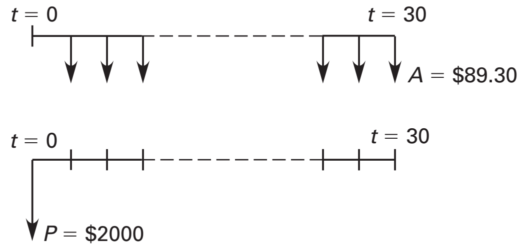
$$(F/P,10\%,10) = 2.5937$$

$$(F/A,10\%,10) = 15.9374$$

$$\begin{aligned} F &= (\$15{,}000)(2.5937) + (\$400)(15.9374) \\ &\quad -(\$900)(15.9374) \\ &= \boxed{\$30{,}937 \quad (\$31{,}000)} \end{aligned}$$

The answer is (B).

16.



From Table 58.1,

$$P = A\left(\frac{(1+i)^n - 1}{i(1+i)^n}\right)$$

$$\frac{(1+i)^{30} - 1}{i(1+i)^{30}} = \frac{\$2000}{\$89.30} = 22.40$$

By trial and error,

$i\%$	$(1+i)^{30}$	$\dfrac{(1+i)^{30} - 1}{i(1+i)^{30}}$
10	17.45	9.43
6	5.74	13.76
4	3.24	17.29
2	1.81	22.40

2% per month is close.

$$i = (1 + 0.02)^{12} - 1 = \boxed{0.2682 \quad (27\%)}$$

The answer is (A).