3.8 A 277-V supply delivers 50 A to a single-phase electric motor. The motor windings cause the current to lag behind the voltage by 30°. Find the power factor and draw the power triangle showing real power $P$(kW), reactive power $Q$(kVAR), and the apparent power $S$(kVA).

\[ S = \sqrt{V I^*} = (277 \angle 0) (50 \angle 30) \]
\[ = 13850 \angle 30° \]
\[ = 11,954 \text{ W} + j 6925 \text{ kVAR} \]

\[ P = 11,954 \text{ kW} \]
\[ Q = 6925 \text{ kVAR} \]

[Diagram of single-phase power triangle]
A 120-V AC supply delivers power to a load modeled as a 5-Ω resistance in series with a 3-Ω inductive reactance. Find the active, reactive, and apparent power consumption of the load along with its power factor. Draw its power triangle.

\[ V = 120 \angle 0^\circ \]

\[ R = 5 \Omega \]
\[ X = 3 \Omega \]
\[ Z = 5 + j3 \]

\[ I = \frac{V}{Z} = \frac{120 \angle 0^\circ}{5 + j3} = 20.57 \angle -30.96^\circ \]

\[ S = VIT = (120 \angle 0^\circ)(20.57 \angle 30.96^\circ) = 2469 \angle 30.96^\circ \]

\[ P = \cos(\theta_V - \theta_I) = \cos(0 - (-30.96)) = 0.8575 \]

\[ Q = \frac{S}{\sqrt{3}} = \frac{2469}{\sqrt{3}} = 1377 \text{ kVAR} \]

\[ S = 2469 \text{ kVA ANS} \]

\[ P = 2117 \text{ kW ANS} \]
A transformer rated at 1000 kVA is operating near capacity as it supplies a load that draws 900 kVA with a power factor of 0.70.

a. How many kW of real power is being delivered to the load?

b. How much additional load (in kW of real power) can be added before the transformer reaches its full rated kVA (assume the power factor remains 0.70).

c. How much additional power (above the amount in a) can the load draw from this transformer without exceeding its 1000 kVA rating if the power factor is corrected to 1.07?

\[ P = VI \cos \theta \]
\[ = (900 \text{kVA}) \times 0.7 \]
\[ = 630 \text{kW} \]
\[ \text{ANS.} \]

\[ P_{\text{max}} = (1000 \text{kVA}) \times 0.7 \]
\[ = 700 \text{kW} \]

\[ \text{CAN ADD} (700 - 630) = 70 \text{kW} \]
\[ \text{ANS.} \]

\[ \theta = \cos^{-1} (0.7) \]
\[ = 45.57^\circ \]

\[ \text{c) \quad P, P \text{ changed to 1} \]
\[ . \quad \text{KW} = \text{kVA} \]
\[ \text{so} \quad 1000 \text{kW} - 630 \text{kW} = \text{370 kVA} \]
\[ \text{ANS.} \]

\[ \text{ADDITIONAL POWER CAN BE ADDED.} \]
3.12 Suppose a utility charges its large industrial customers $0.08/kWh for energy plus $10/mo per peak kVA (demand charge). Peak kVA means the highest level drawn by the load during the month. If a customer uses an average of 750 kVA during a 720-h month, with a 1000-kVA peak, what would be their monthly bill if their power factor (PF) is 0.8? How much money could be saved each month if their real power is the same but their PF is corrected to 1.0?

\[
\text{MONTHLY ENERGY USAGE} = (750 \text{kVA})(720) \]

\[
P = VI \cos \theta = VI(0.8)
\]

\[
= 750 \text{kVA} \times 0.8
\]

\[
= 600 \text{ kw }
\]

\[
W = P \times \text{ TIME} = (600 \text{ Kwh})(720)
\]

\[
= 432,000 \text{ Kwh}
\]

\[
\$W = (432,000)(\$0.08) = \$34,560
\]

\[
\text{PEAK kVA} = \$10 \times (1000) = \$10,000
\]

\[
\text{TOTAL} = \$34,560 + \$10,000 = \$44,560 \text{ ANS}
\]

IF P.F CORRECTED TO 1.0,

\[
P = (600 \text{ kw})(720)
\]

\[
= 432,000 \text{ kw} \leq \text{ REAL POWER UNCHANGED}
\]

\[
\$ KVA \text{ PEAK} = W / \text{ P.F} = 1, \text{ THEN PEAK KVA} = \text{ PEAK KW}
\]

\[
= 800 \text{ kw}
\]

\[
\$ KVA = \$10 \times 800 \text{ kw} = \$8000
\]

\[
\text{TOTAL} = \$34,560 + \$8000 = 42,560
\]

\[\Rightarrow \$2000 \text{ SAVED. ANS}\]
3.13 Consider a synchronous generator driven by a microturbine that delivers power to a strong, balanced, three-phase, wye-connected, 208-V grid (that 208 V is the line voltage). As shown, we will analyze it as if it consists of three separate single-phase circuits.

**FIGURE P3.13a**

a. What is the phase voltage ($V_{\text{phase, grid}}$) for the grid?

b. The following vector (phasor) diagram for one of the phases shows the way the generator is currently operating. Its field current is creating an emf ($E_{\text{GEN}}$) of 130 V at a power angle $\delta = 6.9^\circ$. The current $I_L$ delivered to the grid has a phase angle of $30^\circ$ lagging with respect to the grid. The inductive reactance of the generator armature (stator) windings is $X_L = 0.5 \Omega$, which means the voltage drop across that inductance is $V_L = I_L X_L = 0.5 I_L$. And, of course, current through the inductance lags the voltage across the inductance by $90^\circ$ (ELI the ICE man).

**FIGURE P3.13b**

Under the above conditions, find the following:

b1. The current $I_L$ through the inductive reactance (this means you need to solve the above triangle).

b2. The real power $P$ (W) delivered to the grid by this phase.

b3. The reactive power $Q$ (VAR) delivered to the grid by this phase.

b4. Find the total real power $P$, reactive power $Q$, and apparent power $S$, delivered by all three phases of the three-phase generator.

\[
E_{\text{GEN}} = \frac{V_{\text{phase}}}{\sqrt{3}} = 120 \text{ V, ANS}
\]

\[
\overline{I}_L = 1 \text{ I}_L \angle -30^\circ
\]

\[
E_{\text{GEN}} = 130 \angle 6.9^\circ
\]

\[
\overline{V}_{\text{phase}} = 120.08 \angle 0^\circ
\]

\[
\overline{I}_L = \frac{1}{\sqrt{2}} \left[ E_{\text{GEN}} - \overline{V}_{\text{phase}} \right]
\]

\[
\overline{I}_L = \frac{1}{\sqrt{2}} \left[ 130 \angle 6.9^\circ - 120.0 \angle 0^\circ \right]
\]

\[
\overline{I}_L = 36.10 \angle -30.11^\circ
\]

\[
\overline{I}_L = 36.1 \text{ A, ANS}
\]
\[ P_\theta^{10} = |V_L| |I_L| \cos (69° - (-30°)) \\
= 120 \times (36.2) \cos (30°) \\
= 3.762 \text{ kW} \text{ Ans. To Grid} \]

\[ Q_\theta^{10} = |V_L| |I_L| \sin (69° - (-30°)) \\
= 2.172 \text{ KVAR} \text{ Ans. To Grid} \]

\[ P_{gen}^{10} = |V_{gen}| |I_L| \cos (69° - (-30°)) \\
= (120)(36.2)(\cos (30°)) \\
= 376.2 \text{ kW} \]

\[ P_{gen}^{20} = (3)(376.2) = 11,29 \text{ kW} \]

\[ Q_{gen}^{10} = |V_{gen}| |I_L| \sin (69° - (-30°)) \\
= 282 \text{ KVAR} \]

\[ Q_{gen}^{20} = (3) Q_{gen}^{10} = 847 \text{ KVAR} \]

\[ S^{20} = 3 (P_{gen}^{10} + Q_{gen}^{10}) = 3 (S_{gen}^{10}) \\
= 3 (470 + 36.9°) \\
= 1411 \text{ Kw} \text{ Ans.} \]
A small wind turbine is trying to deliver 30 kW of real power through a 480-V (277-V phase voltage), three-phase power line to a load having a 0.95 lagging power factor. The power line phase has an impedance of 0.05 + j0.1 Ω. What voltage does the turbine have to provide at its end of the power line?

\[ V_e = \bar{I} \bar{Z}_{TL} + \bar{V}_{load} \]

\[ = 387 - 18.19^\circ (0.05 + j1) + 277^\circ 0^\circ \]

\[ = 4.24 (15.24 + j277^\circ) \]

\[ = 280 \angle -617^\circ \]

\[ V_e = \sqrt{3} (280) = 484.9 \text{ V.L.O.} \text{ Ans.} \]

\[ \bar{I} = \frac{P}{V \cos \theta} = \frac{10 \text{ kW}}{(277)(0.95)} = 387 \text{ A} \]

\[ \theta = \cos^{-1}(0.95) = 18.19^\circ \]

**AT WIND TURBINE (L.N)**

\[ \bar{V}_e = 280 \angle -617^\circ \]

\[ \bar{I} = 387 - 18.19^\circ \]