1) [15 pts] A solar panel is rated at \( V_{OC} = 6.6 \, \text{V}, I_{SC} = 15.7 \, \text{A}, \) \( V_{MP} = 5.0 \, \text{V}, \) and \( I_{MP} = 14.0 \, \text{A}. \)
   a) What is the maximum power this panel is capable of producing?
   b) What is the form factor FF for this panel?
   c) If this panel is composed of an array of 6 parallel strings of 12 series cells each, and the area of each cell is 100cm², what is the short-circuit current density \( J_{SC} \)?

\[ \text{5 a) } P_{MAX} = V_{MP} I_{MP} = (5)(14) = 70 \, \text{W}. \]

\[ \text{5 b) } FF = \frac{V_{MP} I_{MP}}{V_{OC} I_{SC}} = \frac{(5)(14)}{(6.6)(15.7)} = 0.675 \]

\[ \text{5 c) } I_{SC} = \frac{15.7}{6(100 \, \text{cm}^2)} = \frac{0.026 \, \text{A}}{\text{cm}^2} \]

\[ \text{260 A/m}^2 \]

2) [5 pts] A solar panel is inclined 30 degrees from horizontal. Calculate the power density in \( \text{W/m}^2 \) on the panel for the case of AM1 sunlight which is directly overhead.

\[ \text{AM1 (1000 W/m}^2 \text{)} \]

\[ \text{Normal component of sun's rays produces} \]

\[ 1000 \cos 30^\circ = 866.7 \, \text{W/m}^2 \]

3) [10 pts] A solar panel has an area of 1.5 m² and the incident light intensity is 5,000 ft-candles. Assuming the efficiency of the panel is 18%, calculate the electrical power output. State any assumptions made.

Assume: 673 lumens/Watt @ \( 7 = 555 \text{nm} \)

\[ 1 \text{ ft-candle} = 1 \text{ lumen/ft}^2 \]

\[ \left( \frac{5000 \text{ lum}}{\text{ft}^2} \right) \left( \frac{3.28 \text{ft}^2}{\text{m}^2} \right)(1.5 \, \text{m}^2) = 80688 \, \text{lumens} \]

\[ \text{5} \]

\[ P_{out} = (80,688 \, \text{lumens}) \left( \frac{673 \, \text{Watt}}{675 \, \text{lumen}} \right) (0.18) = 21.58 \, \text{W} \]

\[ \text{2} \]
4) [15 pts] A copper bar 1.5 meters in length is placed on the table in front of you, and you are holding the ends of the bar. A steady-state B-field of 0.50 T flows upward through the table.

a) As you hold the bar, a DC current of 50 A begins to flow from left to right through the bar. What is the magnitude and direction of the induced force? Will you be strong enough to keep it from moving? [YES!]

b) The current is switched off. Now, still holding the ends of the bar, you push it away from yourself at a speed of 10 m/s. What is the magnitude and polarity of the induced voltage? Is your life in danger from excessively high voltage? [NO!]

\[ F = i \times (l \times B) \]
\[ = 50 \times 1.5 \times 0.5 = 37.5 \text{ N towards you} \]
\[ E_{\text{ind}} = (\dot{V} \times B) \cdot \dot{I} \]
\[ = (10 \text{ m/s}) \times (0.5 \text{ T}) \times (1.5) \]
\[ = 7.5 \text{ V (pos on right end)} \]

5) [15 pts] A 3-phase 2400-V 60-Hz 6-pole synchronous generator has a synchronous impedance of $j15$ Ohms. The terminal voltage of the system is connected to is held constant at 2400 Volts, and it is delivering 250 kW into the 3-phase system grid.

a) Sketch out the per-phase equivalent (phase A - N). $V_T$ has reference angle of $0^\circ$.

b) Calculate the per-phase value of $P_{\text{out}}$. What is the phasor value of $V_T$?

c) The electrical torque angle is known to be $30^\circ$. Calculate the phasor value of $E_A$.

d) Calculate the phasor value of the armature current $I_A$.

\[ P_{\text{out}} = \frac{E_A \cdot V_T \cdot \sin \delta}{X_s} \]
\[ 83.33 = \frac{E_A \cdot (1386) \cdot \sin 30^\circ}{15} \]
\[ \Rightarrow E_A = 1803 \text{ (30° V)} \]

\[ I_A = \frac{E_A - V_T}{jX_s} \]
\[ = 61.2 \angle -11.01^\circ \text{ A} \]
4) [15 pts] A three-phase circuit is shown. Z of each phase of the load is 5 + j3 Ohms.

a) What is the magnitude of \( V_{LL} \) and \( V_{LN} \) on the source side?

\[
V_{LL} = 240 \text{ V} \quad \quad V_{LN} = \frac{240}{\sqrt{3}} = 138.6 \text{ V}
\]

b) What is the magnitude of \( V_{LL} \) and \( V_{LN} \) on the load side?

\[
V_{LL} = 120 \text{ V} \quad \quad V_{LN} = \frac{120}{\sqrt{3}} = 69.3 \text{ V}
\]

c) What is the RMS magnitude of the line current on the load side?

\[
I_L = |\bar{I}_a| = \frac{69.3}{\sqrt{3}} = 11.9 \text{ A}_{RMS}
\]

d) What is the RMS magnitude of the phase current in the delta winding?

\[
I_a = |\bar{I}_{ba}| = \frac{11.9}{\sqrt{3}} = 6.86 \text{ A}_{RMS}
\]

e) What is the RMS magnitude of the line current on the source side?

\[
I_L = |\bar{I}_a| = \frac{120}{240} \times 11.9 = 5.95 \text{ A}_{RMS}
\]

f) What is the "phase shift" of this transformer? What are turns ratios \( a \) and \( a_{eff} \)?

\[
a = \frac{138.6}{120} = 1.155
\]
\[
a_{eff} = \frac{240}{120} = 2
\]

g) Determine the phasor voltage \( \bar{V}_a \) at the load.

\[
\bar{V}_a = 69.3/60^\circ \text{ V}_{RMS}
\]

h) Determine the phasor current \( \bar{I}_a \) flowing into the load.

\[
\bar{I}_a = \frac{\bar{V}_a}{Z} = \frac{69.3 (60^\circ)}{5 + j3} = 11.88 (29.04^\circ) \text{ A}_{RMS}
\]

i) Determine the phasor line current \( \bar{I}_a \).

\[
\bar{I}_a = \bar{I}_a \div 2, \text{ shifted ahead } 30^\circ
\]
\[
\Rightarrow \bar{I}_a = 5.95 (59.84^\circ) \text{ A}
\]
7) [15 pts] Short essay. Answer 3 of the following 4 questions. Clearly mark which one you decide not to answer, else the first 3 will be graded! Explain using 2 or 3 concise sentences. It may be very helpful to make a sketch or provide a key equation as part of the explanation.

a) What are the advantages of a KOH battery electrolyte over sulfuric acid?
   - Electrolyte specific gravity (ion concentration) does not change with charge. (Also means won't freeze).
   - Don't have to test specific gravity.
   - No sedimentation/precipitates.
   - No equalize charging, since no stratification. etc.

b) When talking about photo-voltaics, explain what a "concentrator" array is.
   A parabolic reflector "trough" concentrates sun's rays to be much higher than AM1.

   ![PV Panel](image)
   reflector / concentrator. Multi-layer PV cells operate at higher \( N \). (Also higher Temp)

   ![Multi-layer PV cells](image)

   ![Electrical Circuit](image)
   Proton Exchange Membrane allows protons to pass thru. Electrons flow around thru.
   \( \text{electrical circuit. } + + (+) + O_2 \rightarrow H_2O \).

   ![Electrical Circuit](image)

   How does a fuel cell work?

   ![Fuel Cell](image)

   H_2 \rightarrow H_2O \text{ Vapor}

   I- \rightarrow O_2

   Proton Exchange Membrane allows protons to pass thru. Electrons flow around thru.

   ![Electrical Circuit](image)

   For balanced 3-ph systems/loads/devices, it's easier to calculate P,Q,S,V,I for just one of the phases, which represents 1/3 of P,Q,S and the phase V and I. Typically, a L-N equivalent is chosen. (see problem 5 for example).