LAST NAME SOLUTION FIRST NAME__________ Alphabetic # __________

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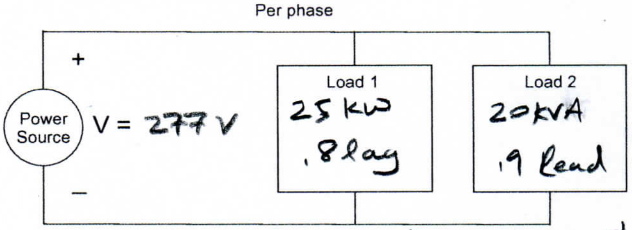
Midterm Exam 1, Spring 2018

1. (25 pts) Two balanced 3-phase Y-connected loads are connected in parallel. Load 1 is draws 75 kW (3-phase) @ 0.8 power factor lagging. Load 2 draws 60 kVA (3-phase) at 0.9 power factor leading. The supply is 480 V (line-line), 60 Hz. Assume that the transmission line is ideal. Use the "a phase" voltage as the $\angle 0$ reference.



a. (2 pts) Compute the per phase voltage.

$$V_{\ell\ell} = \frac{480}{\sqrt{3}} = \underline{\underline{277\,V}} \quad \text{ANS.}$$

b. (6 pts) Compute the per phase real and reactive power associated with each load?

$\theta_1 = \cos^{-1}.8 = 36.9°$ $\theta_2 = \cos^{-1}.9 = 25.8°$

LOAD 1

$P = \underline{\underline{25\,kW}}$

$VI = \frac{P}{pf} = \frac{P}{\cos\theta_1} = \frac{25\,kW}{.8} = 31.25\,kVA$

$Q = VI \sin\theta_1 = 31.25K \cdot \sin 36.9° = \underline{\underline{18.7\,kVAR}}$ ANS.

LOAD 2

$P = VI \cdot pf$

$= 20\,kVA \cdot .9$

$= \underline{\underline{18.0\,kW}}$ ANS.

$Q = VI \sin\theta_2$

$= 20\,kVA \sin(25.8°)$

$= \underline{\underline{8.704\,kVAR}}$ ANS.

c. (4 pts) Compute the current through each load.

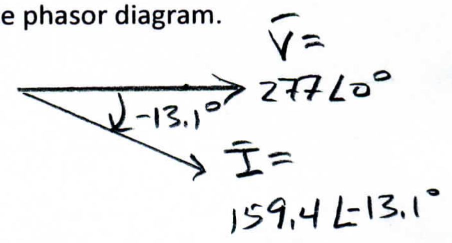
$$I_1 = \frac{P_1}{V\cos\theta_1} = \frac{25\,kW}{277(.8)} = \underline{\underline{112.8\,A}} \quad \text{ANS.}$$

$$I_2 = \frac{P_2}{V\cos\theta_2} = \frac{18\,kW}{277(.9)} = \underline{\underline{72.2\,A}} \quad \text{ANS.}$$

d. (4 pts) Compute power source current phasor. Draw and label the power source phasor diagram.

$$\bar{I}_s = \bar{I}_1 + \bar{I}_2 = 112.8\angle{-36.9} + 72.2\angle{+25.8}$$

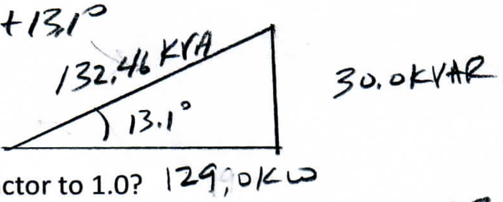
$$= \underline{\underline{159.4\angle{-13.1°}\,A}} \quad \text{ANS.}$$



e. (4 pts) Draw and label the power source's 3-phase power triangle.

1ϕ: $\bar{S} = \bar{V}\bar{I}^* = 277\angle 0°(159.4\angle{+13.1°}) = 43.0\,kW + 10.0\,kVAR$

$3\phi = 3 \cdot 1\phi = 129.0\,kW + 30.0\,kVAR = 132.46\angle{+13.1°}$

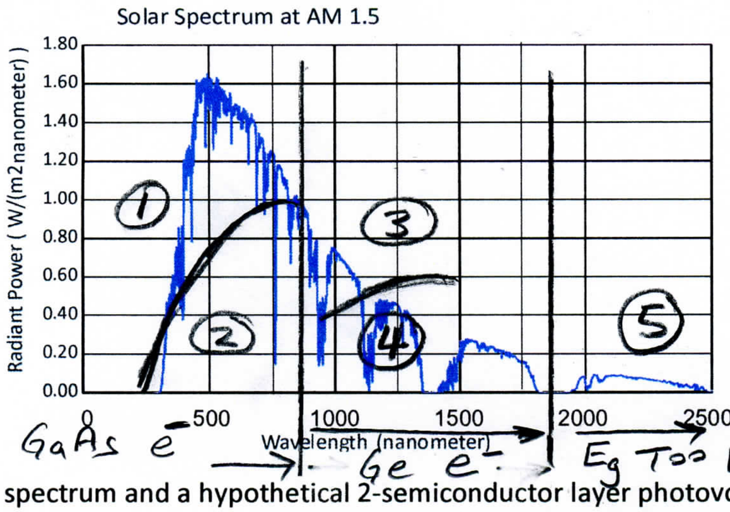


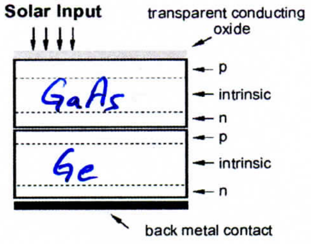
f. (5 pts) What must be done to correct the overall system power factor to 1.0?

ADD CAPACITANCE IN // w/ 2 LOADS THAT SUPPLIES 30.0 KVAR (i.e. CANCELS 30.0 KVAR DRAWN BY NET INDUCTIVE LOAD.

NAME SOLUTION

2. (25 pts)





$h = 6.26x10^{-34}\ \frac{J}{s}$

$c = 3x10^{8}\ \frac{m}{s}$

$1\,eV = 1.6x10^{-19}\ J$

$E_{eV} = \frac{1.243}{\lambda}$

The solar spectrum and a hypothetical 2-semiconductor layer photovoltaic cell are shown (left and right respectively). The semiconductors are GaAs and Ge with band gap energies 1.4 *eV* and .67 *eV* respectively.

a. (6 pts) Label your proposed GaAs and Ge layering for the most effective PV cell. Explain your reasoning.

- GaAs HAS HIGHER E_g than Ge ⇒ 1st LAYER
  IN GaAs PHOTONS w/ $E \geq 1.4eV$ EXCITE e^- INTO CONDUCTION BAND
  MINIMIZES $E \geq 1.4eV$ DISSIPATED AS HEAT.
- PHOTONS W/ $E < 1.4eV$ TRANSIT GaAs. PHOTONS w/ $.67eV \leq E < 1.4eV$
  EXCITE e^- INTO CONDUCTION BAND

b. (10 pts) On the solar spectrum graph, sketch and label (w/ numbers) **(1)** the ***2 regions*** in which light energy is **converted** to **electrical energy** *and* **(2)** the ***3 regions*** in which **light energy** is **dissipated as heat.** Using the number references, briefly explain the energy conversion or dissipation process occurring.

① $E >$ GaAs's $E_g = 1.4eV$ – DISSIPATED AS HEAT; e^- EXCITED TO COND. BAND

② GaAs CONVERTS E INTO ELECTRICAL E; e^- EXCITED TO COND. BAND

③ $E >$ Ge $E_g = .67eV$ – DISSIPATED AS HEAT; e^- EXCITED TO COND BAND

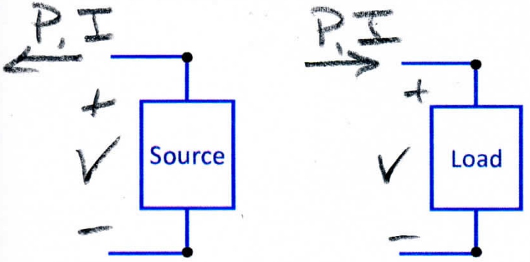
④ Ge CONVERTS E INTO ELECTRICAL E; e^- EXCITED TO COND BAND

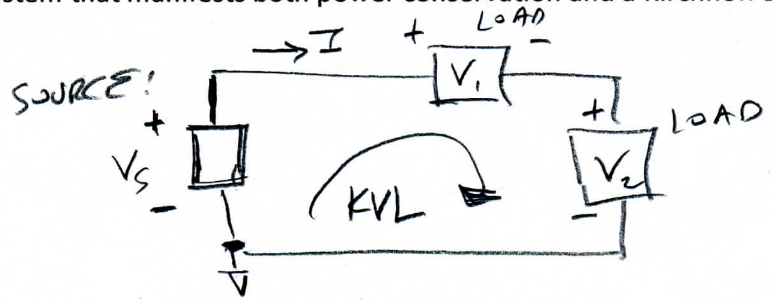
⑤ PHOTON ENERGY DISSIPATED AS HEAT; $E <$ Ge's .67eV INSUFFICIENT TO EXCITE e^- TO COND BAND

These questions are not related to questions a&b above.

c. (6 pts) Label the diagrams to show the load power convention for a source and a load.

d. (3 pts) Sketch and label a closed loop system that manifests both power conservation and a Kirchhoff Law.



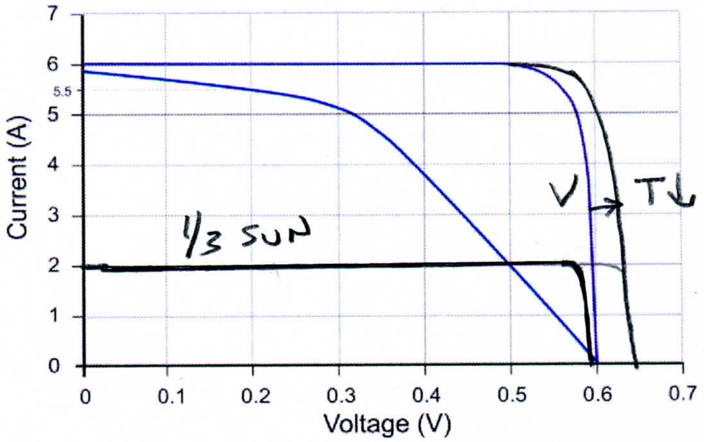


$0 = (-V_s + V_1 + V_2) I$

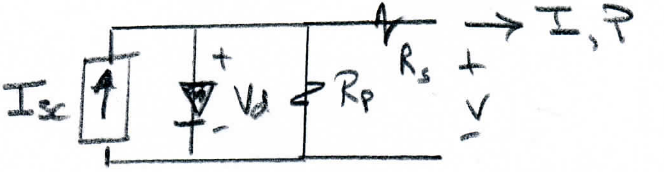
NAME SOLUTION

1. The diagram is the I-V characteristic curves of a PV cell at 1 sun insolation and 25 °C.

- Lower curve is the equivalent circuit I-V characteristic with $R_p = 1\ \Omega$ and $R_s = .05\ \Omega$.



a. (5 pts) Draw and label the equivalent circuit model using accepted variable names.



b. (3 pts) What is the benefit of using the more complex circuit model?

ALLOWS THE MODEL TO STILL BE USEFUL WHEN A CELL FAILS OR IS DEGRADED (SAY BY SHADE OR MALFUNCTION) CURRENT CONTINUES TO FLOW - CAPTURING PV MODULE FUNCTION IN DEGRADED STATE

c. (3 pts) Sketch and label the ideal $\frac{1}{3}$ sun *I-V* characteristic circuit on the figure.

d. (5 pts) For solar insolation of $\frac{1}{3}$ sun, compute the change in V_{OC} for the ideal *I-V* characteristic.

$$I = I_{sc} - I_o(e^{qV/kT} - 1)$$

WHEN OPEN CIRCUIT, $I = 0$

$$I_{sc} = I_o(e^{qV/kT} - 1)$$

$$\frac{I_{sc1}}{I_{sc1/3}} = \frac{\cancel{I_o}(e^{qV_1/kT} - 1)}{\cancel{I_o}(e^{qV_2/kT} - 1)}$$

$$\frac{I_{sc1}}{I_{sc1/3}} \approx e^{q(V_1 - V_2)/kT}$$

$$\frac{6}{2} \approx e^{38.9(V_1 - V_2)}$$

$$V_1 - V_2 = \frac{\ln 3}{38.9} = \underline{\underline{.028V}} \text{ ANS.}$$

[FOR REGION OF INTEREST, $e^{qV/kT} >> 1 \Rightarrow e^{qV/kT} - 1 \approx e^{qV/kT}$]

e. (4 pts) For the 1 sun ideal I-V characteristic, sketch and label the effect of the ambient temperature dropping enough for a noticeable change.

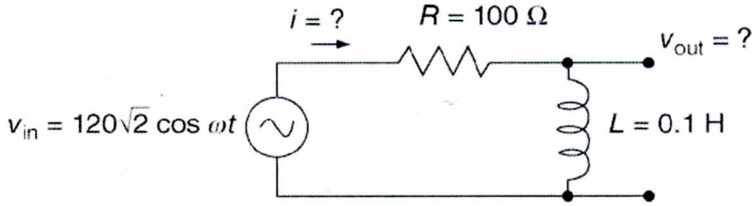
TEMPERATURE DROP CAUSES THE VOLTAGE TO INCREASE.

f. (5 pts) Outline the concept of balancing energy supply and demand. Describe normal load fluctuations and the affect that energy imbalances have on system frequency.

CONSERVATION OF ENERGY / POWER REQUIRES THAT ENERGY CONSUMED + TRANSMISSION LOSSES MUST BE MATCHED BY ENERGY INTO THE SYSTEM.

WHEN CONSUMPTION + LOSSES > GENERATION, f DECREASES
" " " < GENERATION, f INCREASES.

NAME SOLUTION



4. (25 pts) Reference figure above. The system frequency is 60 Hz.

a. (4 pts) What is the complex circuit impedance, $\mathbf{Z_c}$? $\bar{Z} = 100 + j\,2\pi f L$

$$= \underline{\underline{100 + j\,37.7\ \Omega}}\ \text{ANS.}$$

b. (4 pts) Write the phasors $\bar{\mathbf{V}}_{in}$ and $\bar{\mathbf{I}}$. $\bar{V}_{IN} = 120\angle 0^\circ$

$$\bar{I} = \frac{\bar{V}_{IN}}{Z_c} = \frac{120\angle 0^\circ}{(100 + j\,37.7)} = \underline{\underline{1.12\angle -20.6^\circ\ A}}\ \text{ANS.}$$

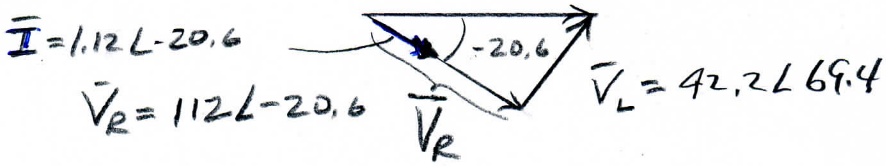
c. (4 pts) Compute ***i(t)***. $i(t) = \sqrt{2}\cdot 1.12\cos(2\pi f t - 20.6^\circ)$

$$= \underline{\underline{1.58\cos(377t - 20.6^\circ)\ A}}\ \text{ANS.}$$

d. (5 pts) Draw a phasor diagram expressing KVL graphically for this circuit

$$V_L = \bar{I}\,jX_L = \bar{I}\cdot j37.7 = (1.12\angle -20.6)\cdot j37.7 = 42.2\angle 69.4^\circ$$

$$\bar{V}_{IN} = \bar{V}_R + \bar{V}_L$$



e. (4 pts) What power does the voltage source deliver?

$$P = VI\cos\theta = (120)(1.12)\cos 20.6 = \underline{\underline{125.8\ W}}\ \text{ANS.}$$

f. (4 pts) What are 2 DoE SunShot Initiative aims?

- REDUCE COST OF SOLAR POWER BY 50% BETWEEN 2020 + 2030
- REMOVE BARRIERS TO ENTRY TO SOLAR POWER USE + INSTALLATION.