Solutions.

ENGR290: Renewable Energy

Midterm Exam

Oct 24, 2013

Problem 1: Energy calculations

(a) To celebrate their outstanding performance on the Midterm exam, Mr West invites all of his SIPI students to his house for movie night, and of course you can't have movies without popcorn! His 1200W microwave oven takes 2.5 minutes to pop one bag of Orville Reddenbacker Movie Theater Butter popcorn and they will eat 4 bags. How much energy will popping the popcorn take (kWh)? 0.2 kWh.

$$1200\,W \quad \frac{2.5\,m}{bag} \quad \frac{1\,hr}{60\,m} \quad 4\,bags = 200\,Wh$$

(b) The big screen TV and DVD player burns 250W of power and the Muppet Movie lasts 1 hour and 45 min. How much energy will watching the movie burn (kWh)? 0.44 kWh

$$250\,W \cdot 1.75\,h = 440\,Wh$$

(c) PNM charges $\$0.13/kWh$. Mr. West is a cheapskate because he is saving all his money for his beach condo in the Dominican Republic so he needs the students to pay for the movie night electric bill. How much does he need to charge each of the 4 students to pay for the electricity? \$0.02.

$$(.2\,kWh + .44\,kWh)\,\frac{\$.13}{kWh} = \frac{\$0.0832}{4\text{ students}} \approx \$0.02$$

(d) Of course, since he teaches renewable energy, he doesn't buy power from PNM, but instead he has a 12V battery bank and inverter in the garage to power the house. For the movie night:

(a) How much battery capacity does he need (kWh) ? 0.64 kWh

(b) How big do the batteries need to be (Ah)? 53 Ah

(c) What minimum power rating does the inverter need to be (kW)? 1200 W

$$.2\,kWh + 0.44\,kWh = 0.64\,kWh$$

b)

$$\frac{0.64\,kWh}{12\,V} = 0.053\,kAh$$

$$= 53\,Ah$$

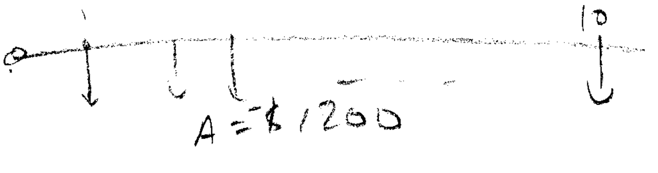
$\frac{25\,kWh}{day}\;\frac{\$.13}{kWh}\;\frac{365\,day}{yr} = \$1200$

Problem 2: Time Value of Money

Mr West calculates that he averages $25kWh$ of electricity each day. PNM charges $\$0.13/kWh$ and pays $\$0.05/kWh$.

(a) How much does his annual electricity cost from PNM? \$1200

(b) Draw a cash flow diagram of his electricity from PNM.



$PV = \frac{1200}{0.149}$ ← 10yr 8% P/A

(c) What is the Present Value of the energy from PNM? \$8100

He is considering installing a net-metered, grid tied PV system (no batteries). The State and Federal Governments give a total of 40% tax credit on the installed system cost. The local provider quotes $\$4/W$ for a $10kW$ system.

(d) How much will the PV system cost before the tax credit is applied? \$40,000

$10kW \;\frac{\$4}{W}\;\frac{1000W}{1kW} = \$40,000$

(e) How much does the government pay? \$16000

$40000 \times 40\% = \$16000$

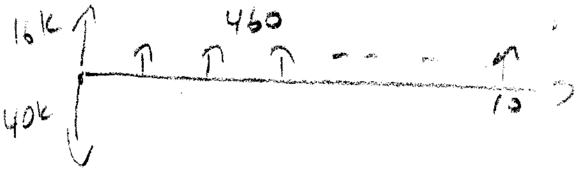
(f) If the PV system produces an average $50kWh/day$ how much energy will he buy/sell to PNM each year ($kWh/year$)? sell 9100 kWh/yr

$\frac{50kWh}{day} - \frac{25kWh}{day} = 25kWh/day \;\frac{365\,day}{yr} = 9100\frac{kWh}{yr}$

(g) How much is that energy worth per year? ($\$/year$)? \$460

$\frac{25kWh}{day}\;\frac{\$0.05}{kWh}\;\frac{365\,day}{yr} = \$456$

(h) Draw a cash flow diagram of his PV system.



(i) What is the present value of the PV system? -\$21000

$16000 - 40000 + \frac{460}{0.149} = \$21000$

Problem 3: Energy Density of Fuels and Efficiency

Since he saved up money by charging his students for movie night, Mr West can afford to buy a nice new RV. Of course he takes his TV, DVD player and microwave with him so that he can eat popcorn and watch the Muppet Movie by himself in the forest. His RV averages $2kWh/day$ of electrical load, and he powers it from a gas generator that is 30% efficient. The energy density of gasoline is $60MJ/l$.

(a) How much gas does he need to take to run the generator for one week of camping (l)? 2.8 l

$$\frac{2\,kWh}{day}\ \frac{7\,days}{wk}\ \frac{l}{(60\cdot 30\%)\,MJ}\ \frac{J}{W\cdot s}\ \frac{3600\,s}{h}\ \frac{1M}{1000k} = 2.8\,l$$

(b) His RV is about as aerodynamic as a brick and weighs 10,000kg. Driving at 65 MPH requires $80kW$ to overcome friction and wind resistance. If the overall efficiency of driving his RV is 20%, how many liters of gas will it take to drive to the Jemez mountains 65 miles from his house? 24 l

$$65\,miles\ \frac{h}{65\,miles}\ 80\,kW\cdot \frac{l}{(60\cdot 20\%)\,MJ}\ \frac{J}{W\cdot s}\ \frac{3600\,s}{h}\ \frac{1M}{1000k} = 24\,l$$

Problem 4: Solar Thermal

Mr West decided the RV was too much trouble so he sold it and bought a fantastic hot tub for his back porch so he can relax, watch the Muppet Movie and eat popcorn without having to drive into the forest. But why waste electricity heating water? So he needs you to design him a solar hot tub heater. His hot tub holds $2000l$ of water and is very well insulated. He has enough space on his roof to install a $9m^2$ collector that is 80% efficient. The specific heat of water is $4.2\frac{kJ}{l*°C}$ and the daily solar energy for Albuquerque is shown in Table 1 for a fixed array.

(a) If he fills his tub from the garden hose at 15°C, how much energy will it take to get his tub up to 40°C (kWh)? 58 kWh

40 - 15 = 25°C

$2000 l \cdot 25°C \cdot \frac{4.2\ kJ}{l\ °C} \cdot \frac{W \cdot s}{J} \cdot \frac{h}{3600 s} = 58 kWh$

(b) Using the solar collector, how many days will it take to get his tub up to 40°C? 1.3 days

$58 kWh \cdot \frac{m^2\ day}{6.4 \cdot 80\%\ kWh} \cdot \frac{1}{9 m^2} = 1.3\ days$

(c) If he heats the tub electrically, and PNM charges $\$0.13/kWh$, how much would it cost to heat the tub to 40°C? \$7.54

$58 kWh \cdot \frac{\$.13}{kWh} = \$7.54$

Problem 5: Photovoltaics

Mr West is almost happy, he has his hot tub, his popcorn and his Muppet Movie, but he still has to pay PNM to power his TV, so of course his next step is to go with PV. Since he is busy relaxing in his hot tub, he cannot be bothered with doing calculations, so he decides to make his students do it for him. His daily electrical load is $20kWh$ and he found solar cells that operate at 0.5V and are 15% efficient and are $0.01m^2$ for \$1.2 each.

(a) How many cells should be wired in series to charge his batteries to near 28VDC? 56 cells

28VDC · cell / 0.5V = 56 cells

(b) Based on Table 1 how big does his array need to be to meet his daily energy consumption (m^2)

(a) For a fixed array 21 m²

20kwh / day · m² day / 6.4 · 15% kwh = 21 m²

(b) For a single axis tracking array 16 m²

20kwh / day · m² day / 8.5 · 15% kwh = 15.6 m²

(c) For a dual axis tracking array 15 m²

20kwh / day · m² day / 8.8 · 15% kwh = 15.01 m²

(c) He decides to be fancy and get the dual axis tracking system because it looks cool.

(a) How many cells will it require? 1500 cells

15 m² · cell / 0.01 m² = 1500 cells

but must have strings of 56 for 28V so need

1500 / 56 = 26.8 → 27 strings

= 1512 cells

(b) How much will that cost? \$1800

1500 cells · \$1.2 / cell = \$1800

Array orientation:	Fixed	Single Axis	Dual Axis
Solar Energy Received ($\frac{kWh}{m^2*day}$)	6.4	8.5	8.8
Improvement over Fixed		+33%	+38%

Table 1: Average Daily Solar energy in Albuquerque