ENGR290: Renewable Energy

Homework 3: Solar Energy

Assigned: Oct 3, 2013
Due: Oct, 10, 2013 (Remember, no late homework is accepted)

Notes:

Solar Thermal (book chapter 2)

Of all the energy used in the average household, a large fraction is used to heat water or living spaces. Figure 2.15 in your book claims that 24% of a household energy is spent heating water and 58% is used to heat the house. Here in NM, most of that heating is probably done with natural gas so it is relatively inexpensive, but if this heating is powered by electrical sources, it can represent a large cost. Heating water requires $4.2\frac{kJ}{l{*}^{\circ}C}$ and according to the textbook, the average house (in England) uses $4,000kWh$ per year for household heating.

For example to heat 80 liters of water from 12°C to 60°C requires $80l * 4.2\frac{kJ}{l{*}^{\circ}C} * 48^{\circ}C = 16MJ = 4.5kWh$. If you average $\$80l$ of hot water per day, that represents an annual usage of $1600kWh$. So if you use PNM rates of $\$0.13/kWh$ you would spend about \$200 to heat your water and \$520 to heat your house.

The solar power influx is about $1\frac{kW}{m^2}$ and according to Appendix B in the Photovoltaics book, Albuquerque sees an average of $8.8\frac{kWh}{m^2 * day}$ of useful solar energy. So in theory all of your water heating could be done with only $1m^2$ of solar collection. Although solar electrical systems are only around 15% efficient, solar thermal collection can achieve closer to 80% so for heating applications, solar heating is a very attractive approach.

Example: How much could you spend on a solar heat collection system to replace your water and space heating power consumption and just break even after 10 years (neglect replacement costs)?

1. Draw a cash flow diagram for your current system as shown in Figure 1.
2. From our financial table handout (assuming 8% interest) lookup the P/A factor of 0.1490.
3. Calculate the Present Value = \$520/0.1490 = \$3490.

So it would be a good investment to buy a solar thermal system if it is less than \$3490. (Of course this is a simplified view which does not account for maintenance or replacement of either system.)

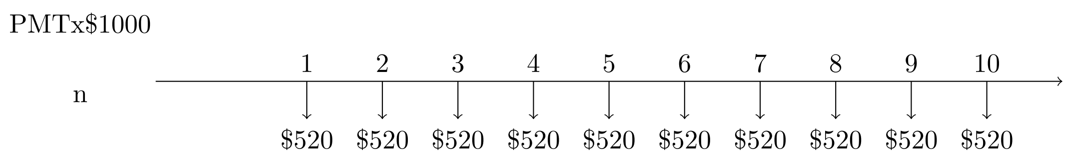

Figure 1: Cash flow for heating system energy costs

Photovoltaics basics (book chapter 3)

PV systems convert solar radiation directly into electrical power. This is accomplished by using the special properties of Silicon solar cells. Most Silicon solar cells produce an open circuit voltage of 0.7V and most cells can produce about 7A of current. So each cell acts as a 0.7V 7 amp source. In order to get useful voltage levels from the cells, they are wired in series into *strings*.

The voltages of cells wired in series add together, so to get up to 14V would require $14V * \frac{1cell}{0.7V} = 20cells$. If each cell produces 7A (cells in series all carry the same current) then a 20 cell *string* would produce $14V * 7A = 98W$.

In order to produce more power at a specific voltage, strings are connected in parallel which adds the currents together. So two 20 cell strings in parallel will provide 14V @ 14A or 196W.

Silicon cells are very expensive so it is possible to reduce the size of the required cells by using concentrators. Concentrators are simply lenses or mirrors used to focus a large area of sunlight onto a small cell. This is very attractive for the reduction in cell area, but it can become expensive due to the high heat generated on the cell and the need for very precise tracking to keep the focused energy on the cell.

It is also possible to increase the production of a PV panel by tracking the sun as it moves across the sky. According to our Photovoltaics book, in Albuquerque a tracking system can increase the output of an array as shown in Table 1.

Array orientation:	Fixed at Latitude	Single Axis	Dual Axis
Solar Energy Received (kWh/day)	6.4	8.5	8.8
Improvement over Fixed		+33%	+38%

Table 1: Average Daily Solar energy in Albuquerque

Problem 1

The average water supply temperature in Albuquerque is 15°C and my water heater is set to 60°C output. I use an average of $100l$ of hot water each day. I am considering replacing my electric water heater with a roof mounted solar heater that costs $2000 to buy and install.

1. Draw a cash flow diagram (10 years annual expenses) for my hot water system assuming PNM charges $\$0.13/kWh$.
2. Draw a cash flow diagram for the solar water heater system (assuming it fulfills all of the water demand and needs no maintenance)
3. Calculate the present value of the two cash flows and decide which is a better investment.

Problem 2

Assume my water heating requirements demand $5kWh$ per day.

1. If my solar water heater collection and storage is 80% efficient, how big (m^2) does my collector need to be?

2. If I were to power this with PV generated electricity, how big would my 15% PV panels (m^2) need to be. To simplify this analysis, assume the electricity can heat the water all day to be used the next morning (no electrical storage needed).

3. Which approach is better and why?

Problem 3

I have a supply of PV panels with the specifications shown in Table 2. I need to build a PV system to drive a 90VDC, 20A water pump for at least 4 hours each day. In order to smooth out the power, I have seven 12VDC, 100Ah batteries in series that need to be charged from the PV to drive the pump.

1. How much energy do I need each day?

2. How many panels do I need (assuming a fixed array)?

3. How should I wire the panels? (How many panels in a string? How many strings in parallel?)

Spec	Value
Efficiency	18%
Voltage	28VDC
Current	7A
Price	$300

Table 2: PV Panel specifications

Problem 4: Extra Credit

Based on the design in Problem 3, I now want to decide if it makes sense to install a tracking system. An installer gave me a quote that a fixed array mount costs $1000 and requires no maintenance. A single axis tracking mount will cost $2000 up front and $100 per year to maintain. For a 2 axis system the quote was $3000 up front and $150 per year to maintain.

1. Draw a cash flow diagram (25year) and calculate the present value of the single axis tracking system

2. Draw a cash flow diagram (25year) and calculate the present value of the dual axis tracking system

3. Which system (fixed, single or dual tracking) is most economical?