# The Grier Photovoltaic Solar Project

## Updated September 2010

I have come to believe that our society is faced with huge environmental and national security issues that revolve around power use and production. There are numerous articles on these subjects in print and online. I won't repeat the issues and arguments here.

In June of 2007 I decided it was time to put into action a contribution, small though it may be, with the goal to help reduce our dependence on foreign sources of power, **and** to reduce my own "carbon footprint."

I choose to add a 3 kW solar photovoltaic array on my home's roof. There were several considerations that entered into the decision.

- How much roof space receives full sunlight, at least most of the year?
- How much space is required for the DC/AC inverter and other electrical equipment that must be added?
- What physical changes would I have to make to accommodate the system?
- What is the incremental cost for smaller or larger systems?
- And, how much can I afford to spend?

Approximately 50% of my roof received full sunlight, most of the year. The remainder is partially shaded by a large tree in the yard. Naturally, the actual exposure changes with the season.

A 3 kW inverter is a common rating for a single inverter unit. There are smaller inverters, which require less space, but larger installations, typically, would employ multiple inverters – though inverters are availble with ratings of 5 kW or higher. I had a limited amount of space that I was willing to allocate to the inverter and associated electrical equipment, and 3 kW seemed to fit in well.

The solar panels provide DC power to the inverter, and the inverter provides AC power at 240V (nominal) to the electrical grid. A "NET" power meter installed by the power utility monitors net power flow to and from the AC power grid. We pay for electrical power based on this net power measurement.

My home was built in 1972 and has had one replacement roof (second layer of shingles). The most recent roof was over 20 years old, but would be servicable for several more years – I might have been able to put off replacing the current roof for up to ten more years. Roofing replacement involves a complete "tear-off," new underlayment, and shingles. Two shingle layers are the maximum permited by building code, and the additional weight of the solar panels suggests that they should not be added to a two-layer roof, anyway. Also, it would be expensive, and somewhat risky, to add a solar array with the expectation that it would have to be removed and restored in a few years, when roof replacement absolutely had to be done. Thus, I needed a new roof before the solar panels could be installed.

My original AC service power panel (breaker box) had no space for additional breakers. Also, it seemed to be an odd size (160 amp, instead of the more conventional 200 amp service). Thus, my old service panel had to be replaced with a larger panel, to allow for the additions for the new AC input from the inverter, and to accommodate future AC circuits. Also, electrical codes have changed in the years since my home was built. As a consequence substantial additional grounding would have to be added.

There are three fiscal components in paying for the system.

1. Colorado residents passed Amendment 37 in 2004 that required Xcel and other utilities to subsidise PV solar and wind power installations. Xcel implemented its Solar*Rewards program to meet the law's requirements.
2. The Federal Government provides up to a $2000 tax rebate for qualifying systems.
3. I have to pay the balance.

I located several local PV solar companies and sought bids. The last year has seen several new businesses get into the PV market in this area, so choices may well have improved in the last year.

After reviewing the proposals, which included the additonal 200A AC service panel **and** a data logging option ($400-500 extra cost), I found almost a $5000 difference in cost from lowest to highest. I was surprised, and didn't want to simply choose the lowest bid. However, the lowest cost proposal was from a company (Golden Solar LLC) that had done an installation for a friend, who recommended them – always a good thing! So we went with Golden Solar. After signing a contract and providing a deposit, they ordered solar panels, inverter with accessories, and the additional required electrical components; it would take about 30 days to get material delivered and for the installation to be completed. Follow on to that would be approvals by the City of Lakewood Building Department (electrical inspection), and installation of a NET meter by Excel along with a separate contract between us and Excel, so that we could apply the Xcel rebate to the cost. The rebate went directly to Golden Solar so we paid only the balance due when the installation and inspections were completed.

First, I had to schedule the roof tear-off and replacement. I got bids on the job, and also went with the lowest cost bid, coincidentally also recommeded by an aquaintance. The roof replacement cost was $3800.  The replacement roof work was done in July, and the solar installation started in August.

Here are the system specifications:

Fronius IG3000 Inverter

**DC Input Data FRONIUS IG 3000**
Recommended PV power 2500 – 3300 Wp
Max. DC input voltage 500 V 500 V 500 V
Operating DC voltage range 150 – 450 V 150 – 450 V 150 – 450 V
Max. usable DC input current 13.6 A 18 A 16.9 A
**AC Output Data FRONIUS IG 3000**
Maximum output power @40° C 2700 W
Nominal AC output voltage 240 V 208 V
Utility AC voltage range 212 – 264 V (240 V +10% / -12%) 183 - 229 V
Maximum AC current 11.25 A
Maximum utility back feed current 0.0 A 0.0 A 0.0 A
Operating frequency range 59.3 – 60.5 Hz (60 Hz nom)
Total Harmonic Distortion THD < 5%
Power Factor (cos phi) 1
**General Data FRONIUS IG 3000**
Max. efficiency 95.2%
Consumption in stand-by < 0.15 W (night)
Consumption during operation 7 W
Enclosure NEMA 3R
Size (l x w x h) 18.5 x 16.5 x 8.8 inches (470 x 418 x 223 mm)
Weight 26 lbs. (11.8 kg)
Ambient temperature range -5 to 122 °F (-20 to +50 °C)
Cooling controlled forced ventilation
Integrated AC and DC disconnects standard UL approved DC & AC disconnects
**Protections**
Ground fault protection Internal GFDI, in accordance with UL 1741
DC reverse polarity protection Internal diode
Islanding protection Internal, in accordance with UL 1741, IEEE 1547
Over temperature Output power derating
Surge protection Internal DC & AC protection, Tested to 6 kV
**Compliance**
Safety UL 1741
EMI FCC Part 15; Class A & B
Anti-Islanding protection UL 1741, IEEE 1547
Ground fault detector and interrupter Compliant with NEC Art. 690 requirements, UL 1741
**Miscellaneous**
Maximum AC over current protection Two-pole, 15 / 20 A circuit breaker
AC wire sizing Use maximum AWG 6 194°F (90 °C) copper wire
DC wire sizing Use maximum AWG 8 194°F (90 °C) copper wire
AC disconnect 16 A
DC disconnect 25 A
Warranty 10 year Premium Warranty is Standard

In addition, I added a Comm interface and Datalogger box  These components are shown in Figure 1.

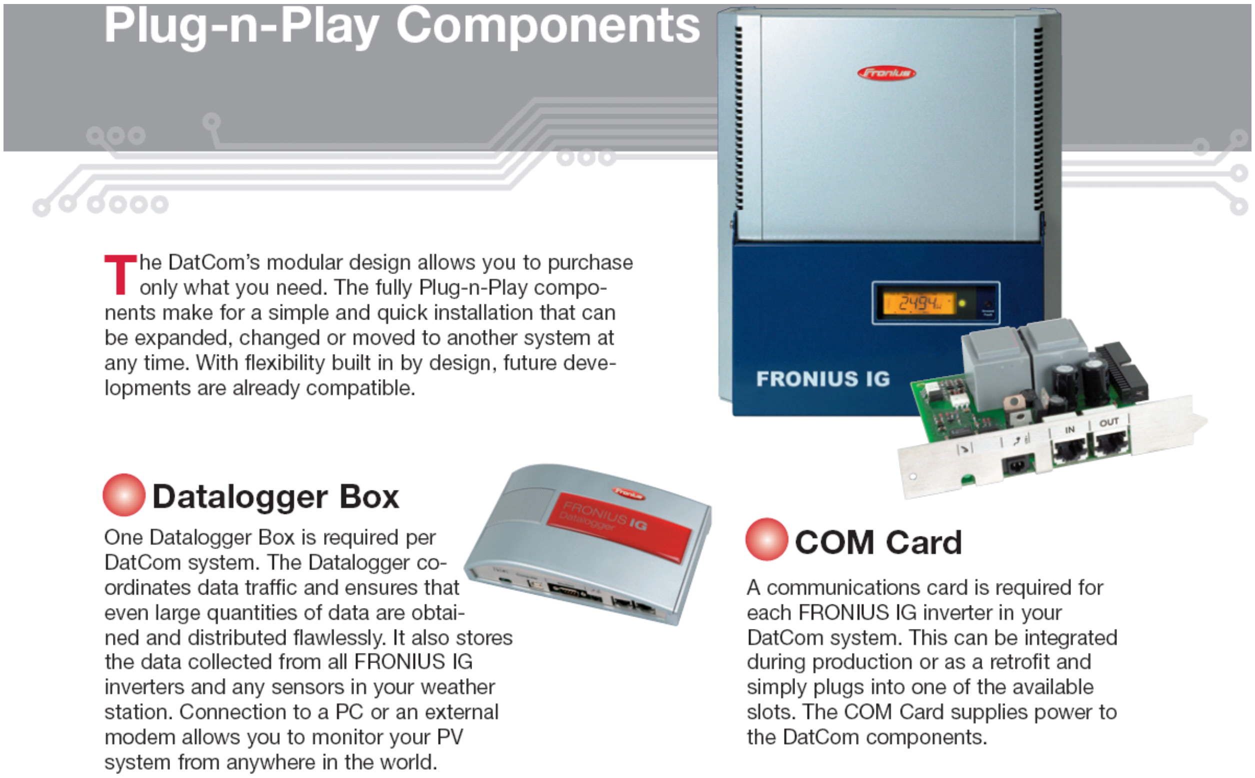


Figure 1

Sharp 170U1 solar panels:

Electrical characteristics:

**Cell** Poly-crystalline silicon
**No. of Cells and Connections** 72 in series
**Open Circuit Voltage (Voc)** 43.2V
**Maximum Power Voltage (Vpm)** 34.8V
**Short Circuit Current (Isc)** 5.47A
**Maximum Power Current (Ipm)** 4.9A
**Maximum Power (Pmax)*** 170W (+10% / -5%)
**Module Efficiency (ηm)** 13.10%
**Maximum System Voltage** 600VDC
**Series Fuse Rating** 10A
**Type of Output Terminal** Lead Wire with MC Connector

Mechanical characteristics:

**Dimensions** 62.01" x 32.52" x 1.81"
1575mm x 826mm x 46mm
**Weight** 37.485lbs / 17.0kg

The total solar array to be installed consisted of 18 Sharp 170U1 panels for a raw maximum power output of 3.06 kW. The AC power conversion efficiency of the Fronius IG 3000 inverter is 95.2% (2.913 kW), but the maximum actual output power rating is 2.7 kW, which agrees quite closely with my observations. Figure 2 shows the panels we used.


Figure 2

Costs

| | |
|---|---|
| Roof replacement | $3800 |
| Solar system, installed | $22490 |
| Xcel Rebate | -$13770 |
| Net "out-of-pocket" | $12520 |
| Federal Income Tax energy rebate | -$2000 |
| Roof replacement less non-amortized value (75%) | -$2850 |
| **Net Total Cost** | **$7670** |

I decided that 25% of the replacement roof cost should be applied to the bottom line. I would not have had to do this part of the job for several years, but eventually roof replacement would have been needed.

Costs, "down the road"

Part of the contract that I signed with Xcel in order to qualify for the rebate was to guarantee that my system would be maintained for 20 years. The waranty period for the solar panels is 25 years, so that part of the system should incur no additional cost. The waranty period for the Fronius inverter, on the other hand, is 10 years. Thus, it is reasonable to assume that it may need repair or replacement during the following 10 years. If I assume that a new inverter will cost $2000, in 2007 dollars (based on the retail cost of my current model), to be “fair and balanced” I should add that cost to my calculated Total Cost. This results in an actual cost of **$8670** in 2007 dollars – the assumption that I’ve made is that there is a 50% probability of failure between system years 10 and 20. Other maintenance costs are possible, but are hard to calculate. So, I won’t bother.

Payback

Electrical power rates are ephemeral at best. That is, the stated rate (September 2008) is about 8.2 cents per kW hour. However, there are charges and fees that are added to each utility bill. Some of these additional fees and charges are fixed, and some vary based on consumption. The consumption-variant fees should be amortized with the actual charges for power, while the fixed fees and charges should not. So, I’ve made the assumption, approximation, WAG, that real power rates as of September 2008 are about 10 cents per kW hour. If rates **never increase** ( a snowball’s chance in hell, that…), my solar system would have to generate 86700 kW hours (86.7 MW). 20 years X 365.25 days = 7305 days. To break-even, in 20 years, my system would have to average 11.87 kW hours per day.

How likely is it that I will break even in 20 years? Based on my first 11+ months of use (about 355 days), my system has generated 4135 kW hours of power. So, my estimate is that a full year’s power production will be about 4150 kW. If this estimate is accurate, I’m right on the cusp at 82000 kW hours for 20 years. Thus, if prices remain constant (impossible), and inflation remains low (unlikely?), it may take between 20 and 21 years for my system to break even.

All things considered, I feel justified, even if some of the justification is warm and fuzzy, rather than cold and calculated. I will update these calculations after a full year of operation.

There are several things to realize. Parts of my system cost may not be incurred by others. I upgraded my AC service panel, some may not need this. This upgrade cost was on the order of $800. I replaced my roof at an estimated cost of $960, and I added communications and datalogging. At an additional cost of about $400. So, perhaps some others might see their own costs lower than mine by as much as $2000. This would reduce the payback by several years. Also, other vendors and manufacturers might be selected resulting in lower (or higher) cost.

Figure 3a

Figure 3b

Figures 3a/b shows the location of the solar array on my home – Figure 3a was taken in early spring, while Figure 3b was taken in late summer (to emphasize a new deck awing). The house orientation is about 35 degrees from north. Thus, the roof has an excellent exposure to sunlight. Both photos show the solar panels that I use for greenhouse ventilation and attic ventilation. These ventilation power panels are not part of this discussion.


Figure 4

Figure 4 shows the Net meter, DC disconnect, inverter, AC disconnect, and AC service panel (from top left, counter clockwise). There also is a weather-proof AC receptacle, middle right. The data communications cable exits the right side of the inverter and pierces the house shell for connection to the data logger box, which is adjacent to the PC that I use for system monitoring. I also have a wireless weather station connected to the same PC so that I can correlate weather data with that from the solar system.

Figure 5

Figure 5 shows the 16 solar panels mounted on the roof.

The DC power from the panels is routed through the conduit that pierces the roof on the lower left side of the panels. The wires in this conduit proceed to the DC disconnect panel so that DC power can be manually removed from the inverter.

The inverter has built-in DC and AC disconnect switches. However, electrical code demands that these disconnect switches are in a separate enclosure. Thus, there is some duplication of function – and cost that, otherwise, might be avoided.

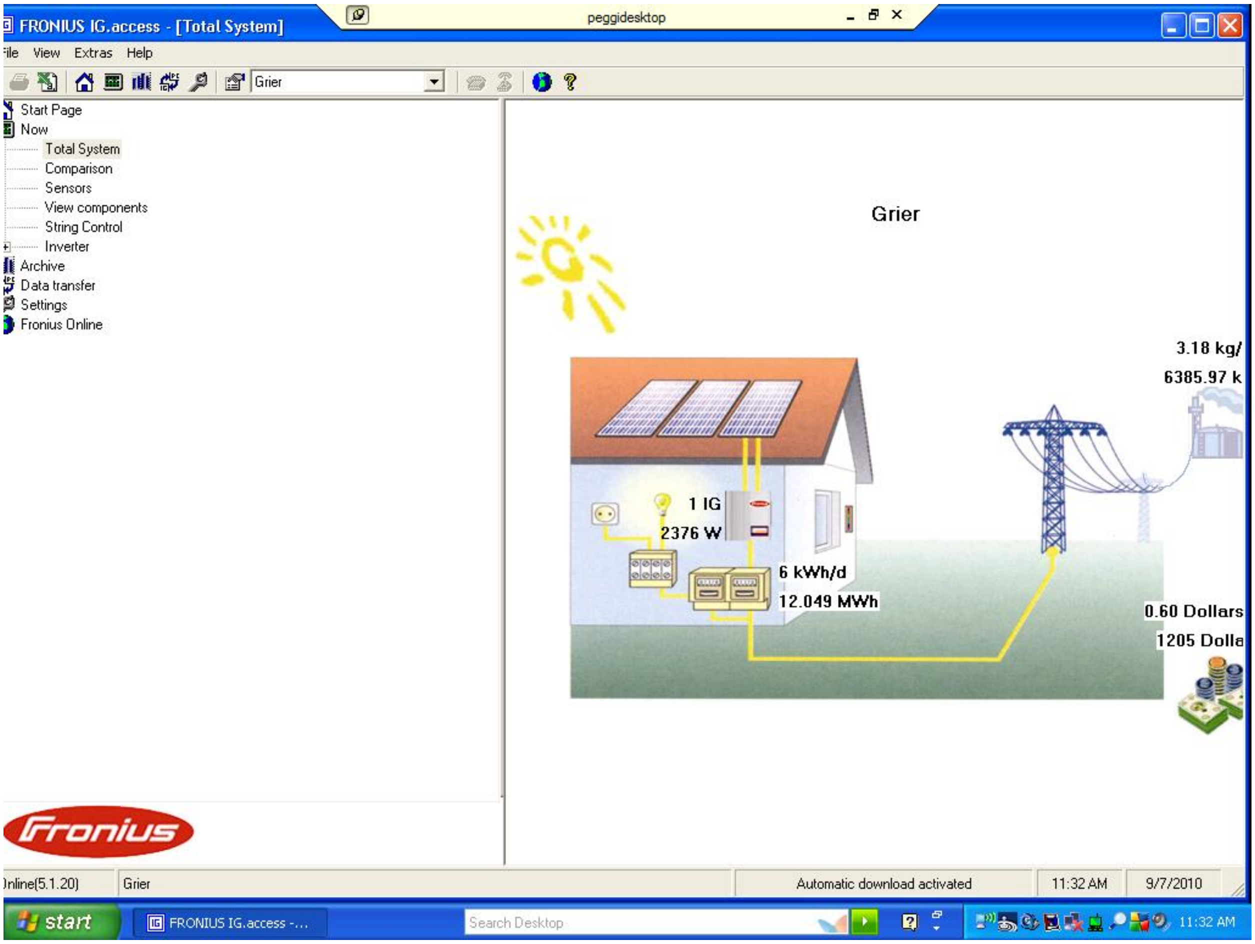


Figure 6 (September 2010)

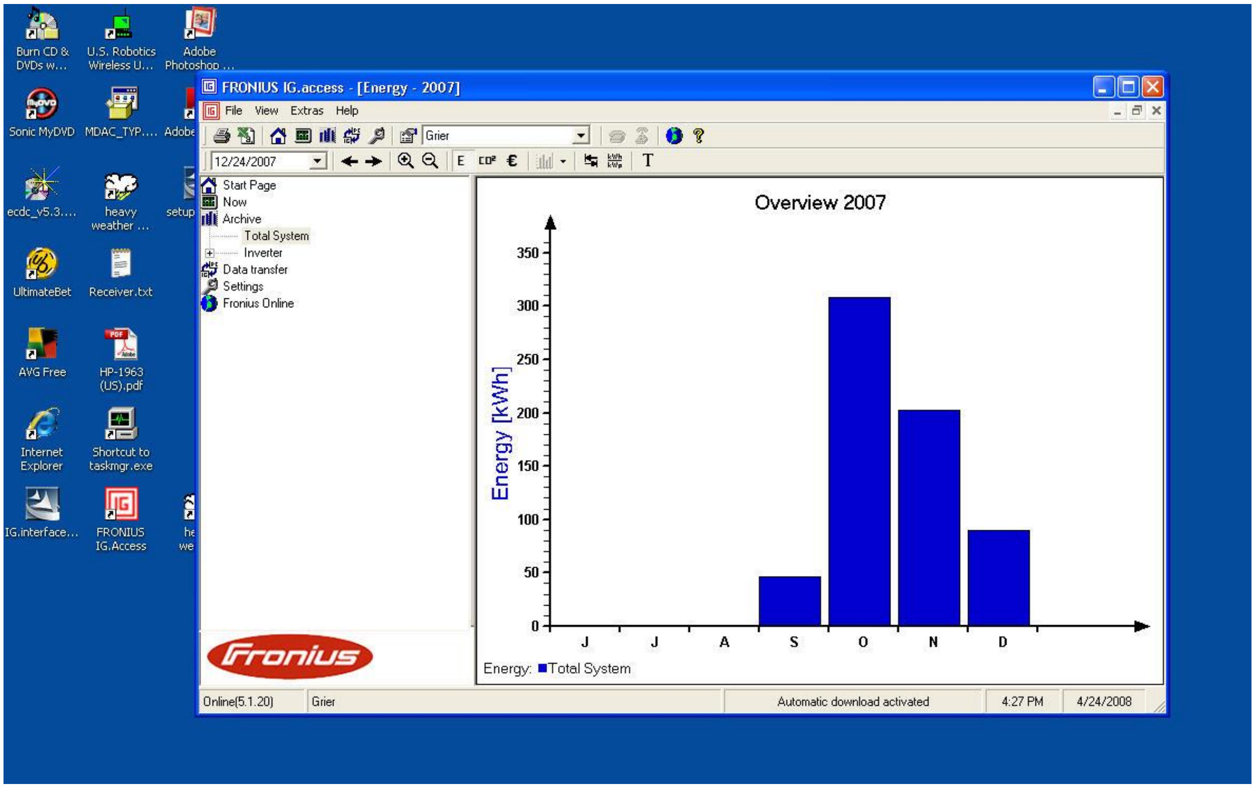


Figure 7

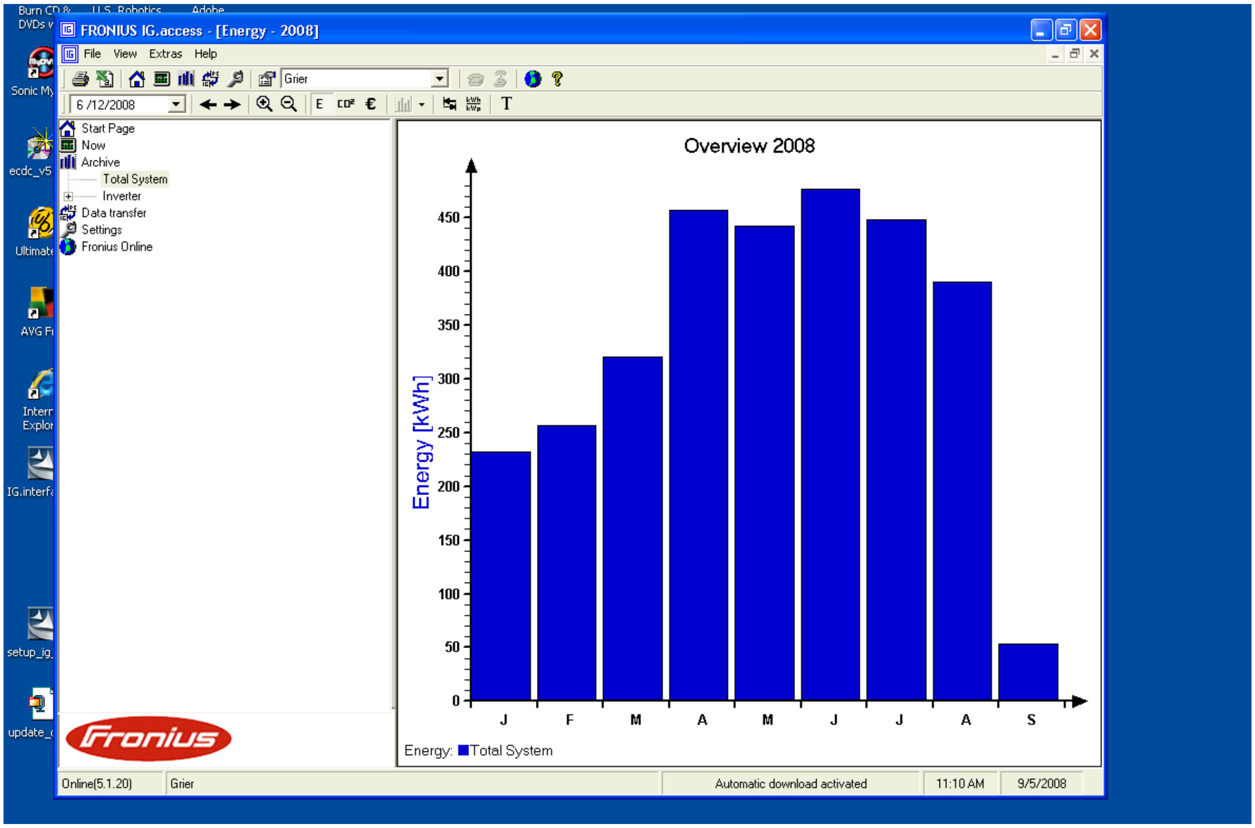


Figure 8

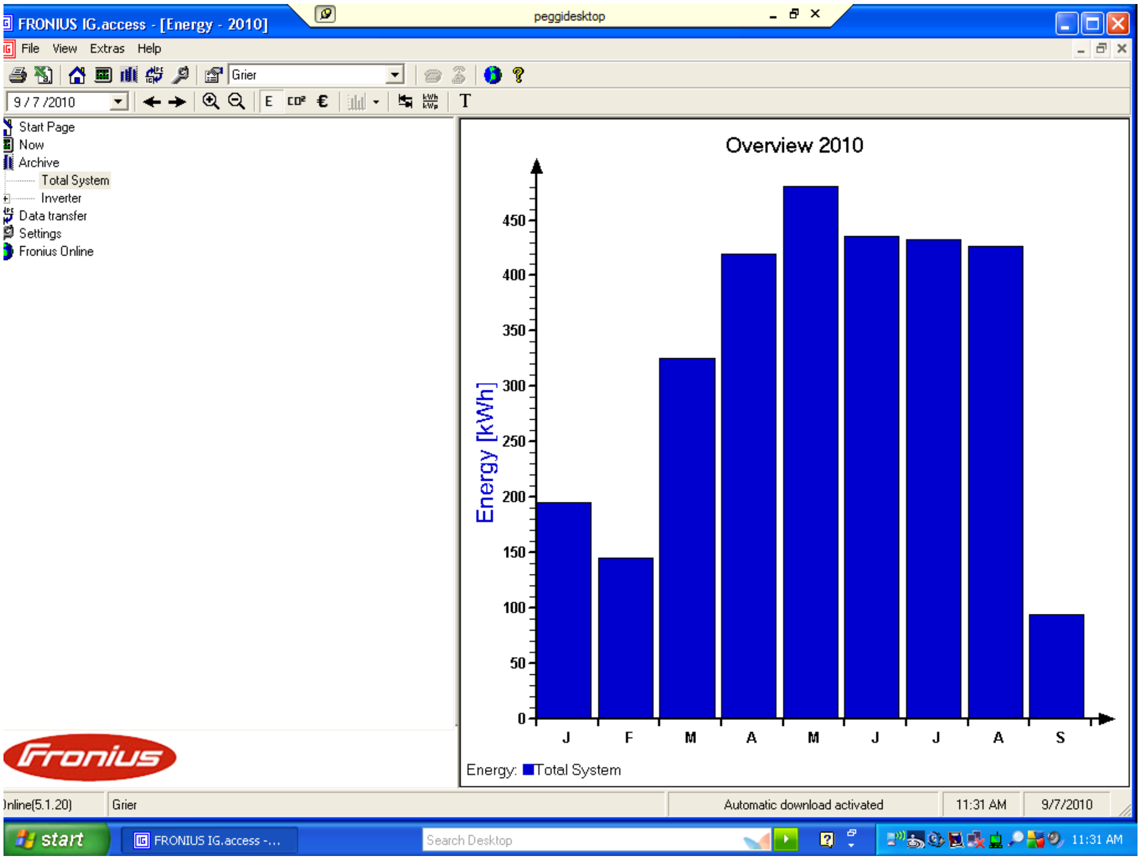
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Figure 9

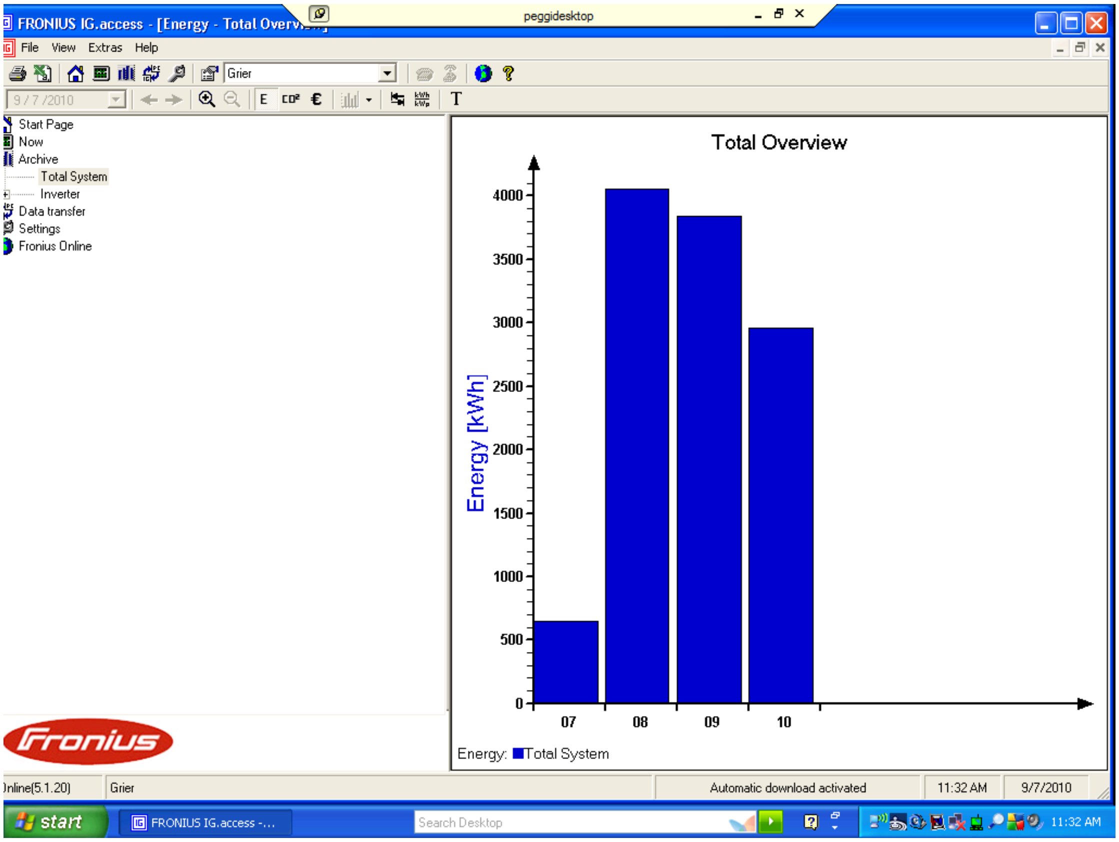


Figure 10

Figure 6 shows a schematic of the system as displayed by the monitoring software provided by Fronius for use with the inverter and data logger. It shows the total power produced over the first three years of operation. This amounts to 12.05 Mwatts (12050 Kwatt hours, to be more specific) to date.

Figures 7 and 8 show net power production for the months of September 2007 (a few days) through early September of 2008. It is easy to see the seasonal variation in power production. The results are a function of average daylight and weather (cloud cover and snow on the panels). Figure 9 shows net power production during 2010 by month, while Figure 10 shows yearly power production. Note, 2009 was slightly lower than 2008, and 2010 may lag 2009. There are two reasons, seasonal variabilty, year over year, and the likelyhood that a tree in our back yard is slightly shading the solar panels during the early mornings. Tree grow will increase and production decrease – unless I decide to remove the tree. A contra-indicator to such removal is the fact that the shade from the tree also decreases solar heating in the home, during the summer, thus reduced air conditioner load might be traded for reduced solar production with no actual loss of total benefit. This calculation is tricky, and I'm disinclined to make it.

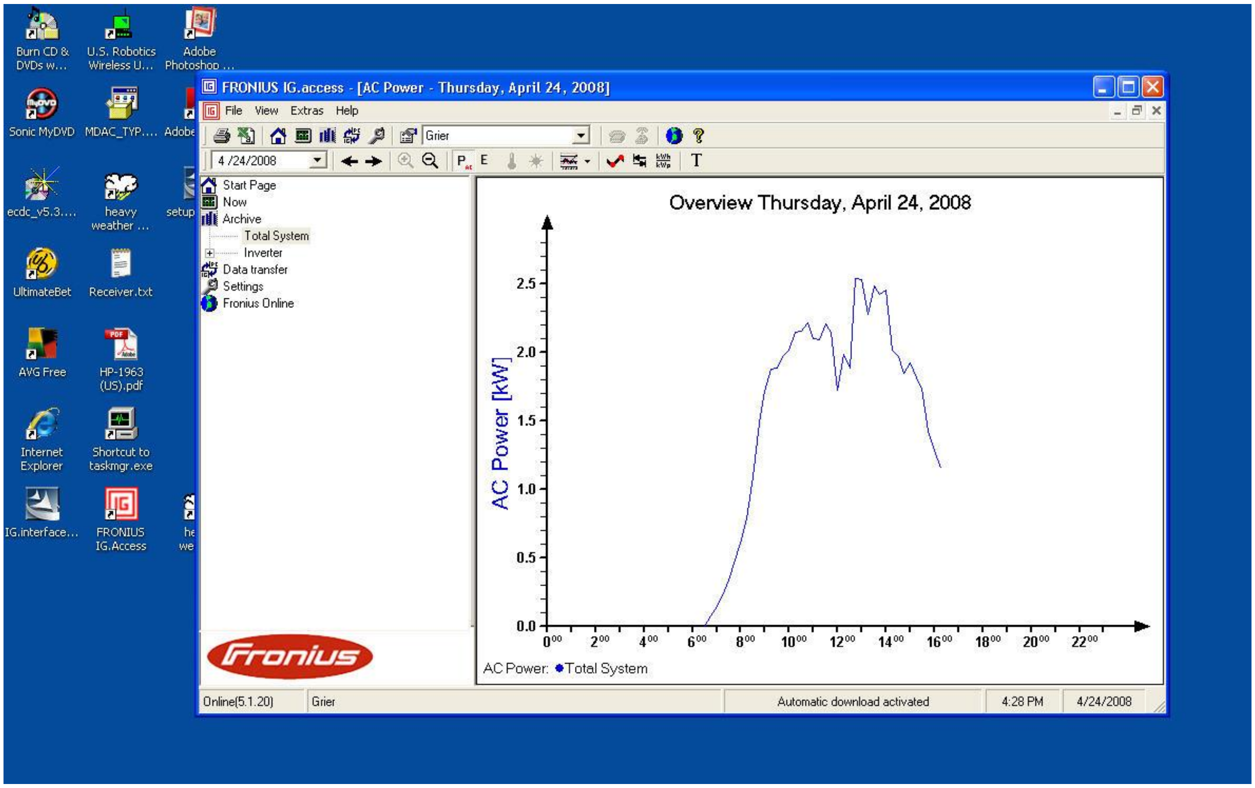


Figure 11

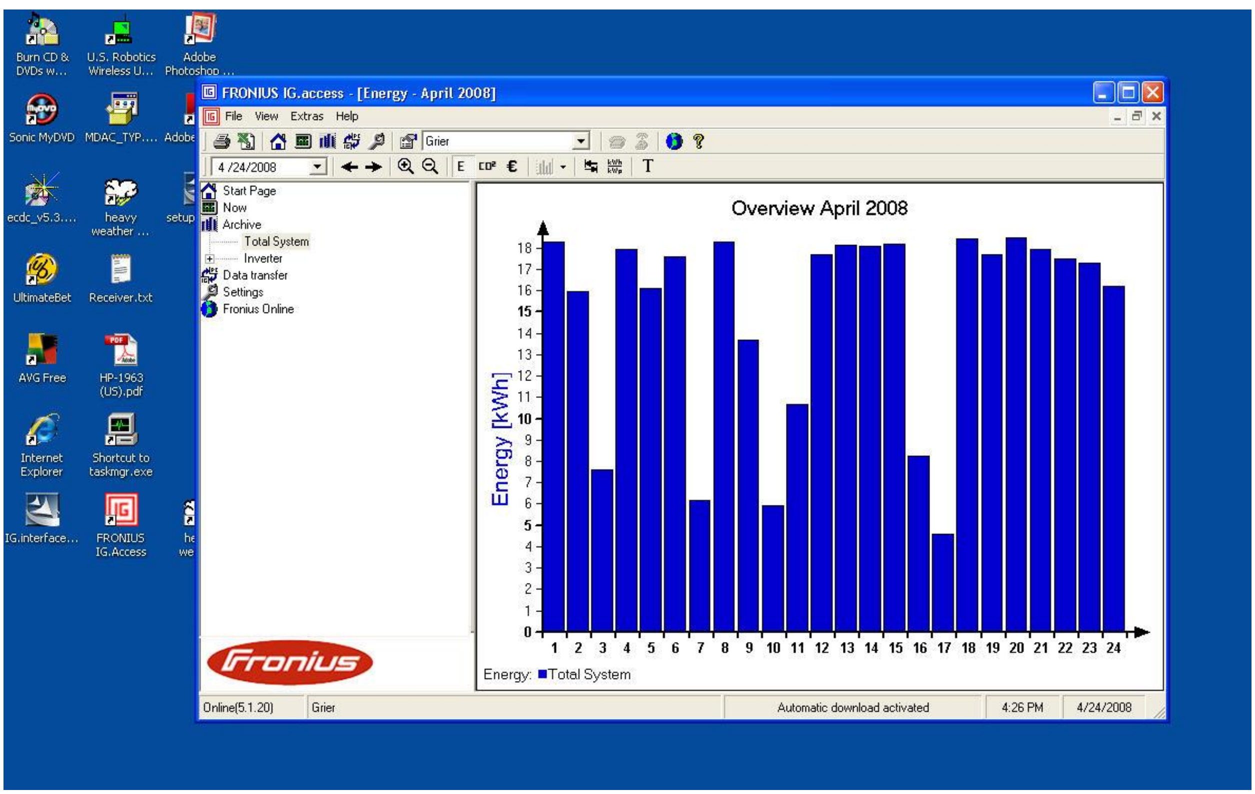


Figure 12

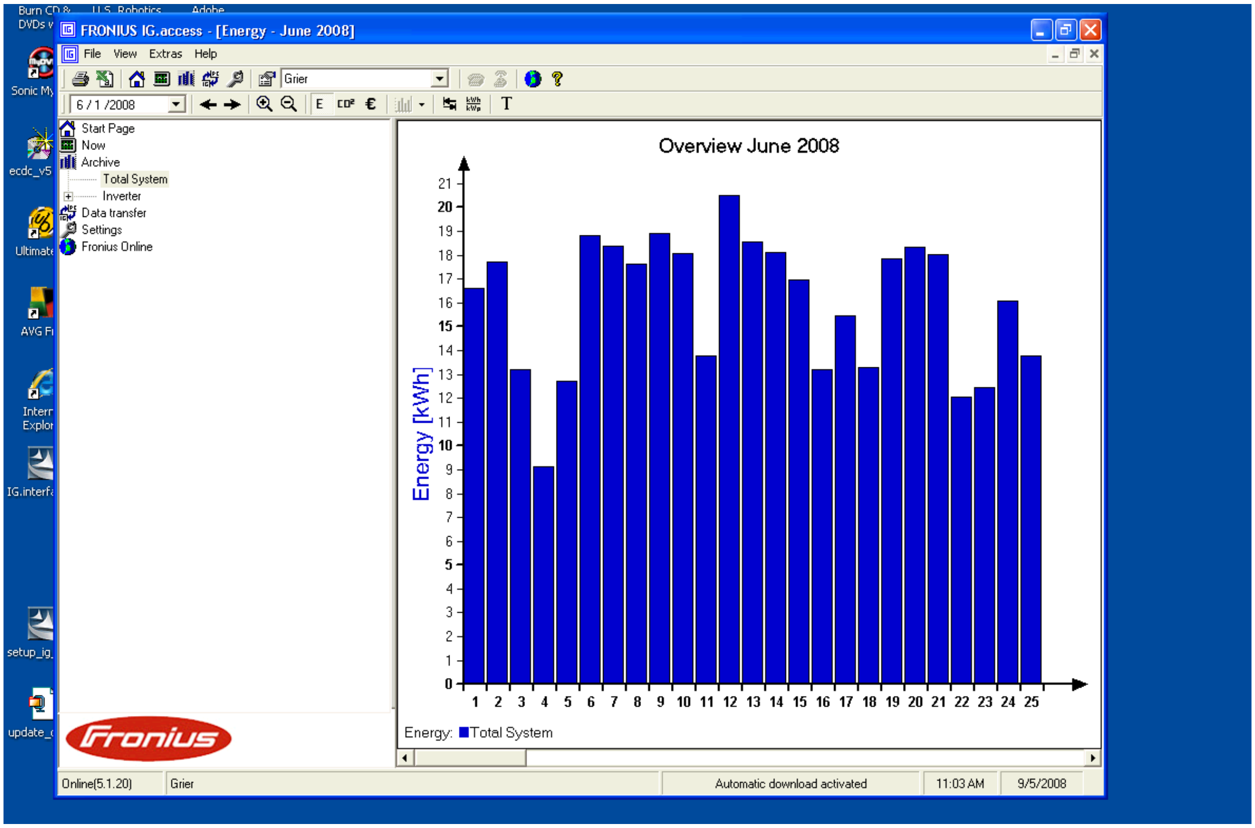


Figure 13

Figure 11 illustrates power production during a single day. Production varied with daylight received as a result of time-of-day, and cloud cover.

Figure 12 illustrates the variation of power production during the month of April. April days in Colorado may be sunny, cloudy, or down-right snowy. This particular April had several days with substantial cloud cover, but very little snow.

Figure 13 illustrates the power production during the month of June. June should be, and was, the month with the highest average power production. The 12th was the day of highest production, at slightly over 20 KW hours. It represented and especially cloudless Colorado day. Figure 12 shows the detail (a single cloud obscured part of the sun at about noon). On the 12th, peak power production was about 2.8 KW.

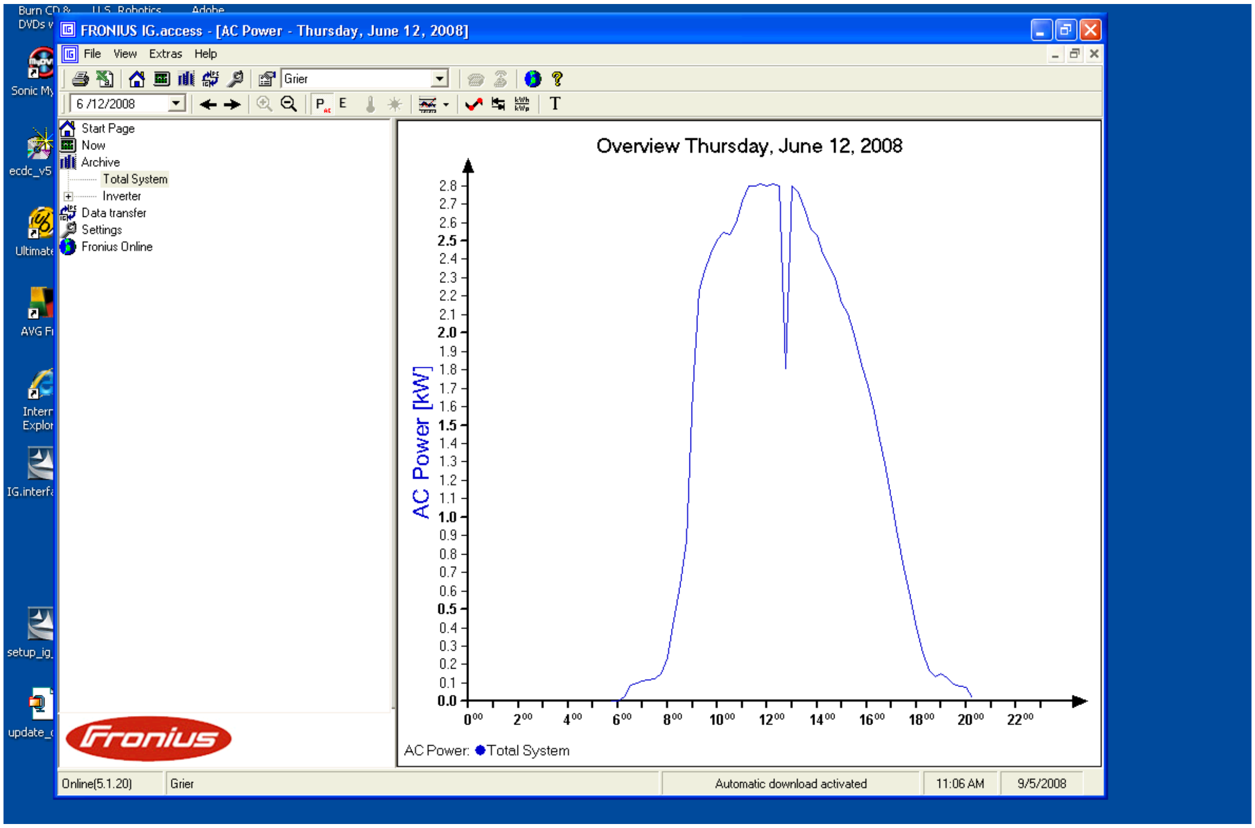


Figure 12

Conclusion:

Our solar system has generated 12.05 Mwatt hours of power, while our net electrical power consumption over the same time period was 16.817 Mwatts of power. Thus, we are generating over 71% of the electrical power that we consume. My goal was 67%, thus we are slightly ahead of my initial target. Not bad!

Also, the cost of electricity continues to increase. A recent estimate that I have read for Xcel (our supplier) states that the actual cost now is 11.2 cents per Kw hour, more than 10% higher than my generous calculation. In addition, Xcel has introduced tiered pricing, where consumption of more than 500 Kw hours during Summer months is billed at 2x. Our use of solar assure that we will never exceed 500 Kw hours in any month; in fact, our net summer production, even with occasional air conditioner use is very close to zero.

My current estimate is that our solar installation will have paid for itself within 17 years, and that the annual ROI (Return on Investment) exceeds 5%.