Thin-Film Photovoltaic System | Electrical Influence

Research

Over the past few years, thin-film technology has become the most efficient solar technology available in the market. As of 2005, 19.5% efficiency was recorded with copper-indium-gallium-selenium (CIGS) photovoltaic cells by a team at the National Renewable Energy Laboratory (Copper indium gallium selenide, 2009). CIGS is a semiconductor light absorbing material that has a specific microstructure allowing the cells to be only a few micrometers thin. As expected, the CIGS thin-film technology has exploded in the solar market and has taken on several forms, including a unique cylindrical shape provided by Solyndra.

Product Selection

Solyndra has utilized the CIGS technology to design, manufacture, and sell cylindrical photovoltaic panels, or tubular solar panels, for low-slope rooftops. Within each panel, sized at 1m x 2m, are (40) – 1 inch diameter cylinders with CIGS thin films rolled inside the cylinders. Contrary to traditional panels (Figure 16 below), the tubular panels are mounted horizontally and laid extremely close to one another, allowing significantly more roof coverage and resulting in a higher production of electricity per rooftop per year (Products, 2009).

Figure 16 - Solyndra panels on left vs. conventional panels on the right.

According to Solyndra, optimum performance can only be achieved when the panels are horizontal to the roof surface.

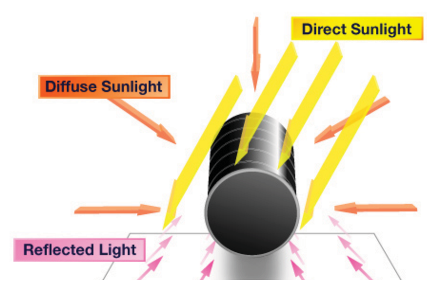

Figure 17 - Solar energy collection of each module.

One of the most unique features of the cylindrical modules is the ability to capture 360-degrees of direct and diffuse sunlight, which allows the system to remain stagnant and not have to track the sun. When combined with a white roof, which reduces building cooling loads, the panels become capable of capturing up to 20% more sunlight from the sunlight that reflects off of the white roof (Solyndra Reveals

Thin-film Solar Tubes, 2008), which in turns produces significantly more electricity per year. Figure 17 to the right depicts the various directions of sunlight that each module can collect.

Figure 18 - Wind design for Solyndra and a conventional system.

Another significant design feature of the tubular panels is its wind performance (Products, 2009). The panels allow wind to blow through the spaces between each module, whereas traditional panels are solid and prohibit wind from passing through the panel. Please see Figure 18 above for an illustration of the two systems. As a result, there is negligible wind loads, both upward and downward, on the roof structure. In fact, the system has significant mass that can sustain up to winds of 130 mph. In addition, this elevated, open configuration optimizes performance for snow loads and other rooftop obstacles.

Design Analysis

Once the solar energy system was chosen, see Appendix F for product data, there were several steps to designing the system for MADC5.

1. Determine the maximum amount of panels that could fit onto the roof, which includes a main roof and a second level mezzanine roof.
    a. Main Roof = 236,000 SF
    b. Mezzanine Roof = 61,000 SF (if necessary)
    c. Panel Size = 6 ft x 3.5 ft = 21 SF

    By simple calculations, leaving extra space for roof obstacles and space between panels, it was determined that the main roof could fit about 11,000 panels and the mezzanine could fit 2,800 panels.

2. Determine the amount of panels in each array. See Figure 19 to the right.
    a. Connected in Series (also known as a Series String)
        i. No. of Panels =

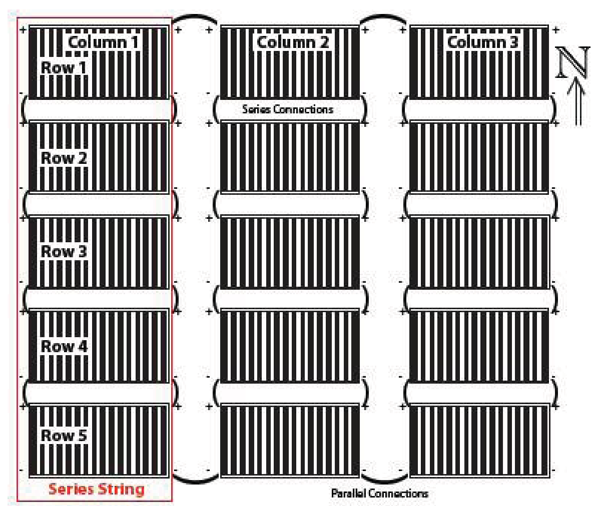

Figure 19 - Series and parallel connections for Solyndra panels

$$\frac{\text{US NEC Rating (V)}}{V_{OC}} = \frac{600\text{ V}}{102.5\text{ V}} = 5.85 = \mathbf{5\ panels}$$

b. Connected in Parallel (Per design guide, up to 3 strings can be placed in parallel.)

i. $\text{No. of Strings} = \left(\frac{I_{fault}}{I_{SC}} + 1.25\right)\left(\frac{1}{2.81}\right) = \left(\frac{23\text{ A}}{2.70\text{ A}} + 1.25\right)\left(\frac{1}{2.81}\right) = 3.47 =$ $\mathbf{3\ Stings}$

3. Determine the amount of panels required to power the building lighting load of 508 kW. It is typical to use more panels to ensure that the load is met.
   a. As determined above, each sub-array consists of 15 panels (5x3). Per supplier, it is typical to place 10 sub-arrays in each array.
   b. $\text{No. of Arrays} = \frac{508\text{ kW}}{27.3\frac{\text{kW}}{\text{array}}} = 18.6 = \mathbf{19\ array}$
   c. $\text{No. of Panels} = (19\text{ arrays})\left(150\ \frac{\text{panels}}{\text{array}}\right) = \mathbf{2850\ panels} \ldots \mathbf{518.7\ kW\ power}$
   d. By a comparison to the allowable amount of panels, it can be determined that there is ample room for the panels to power the lighting load.
4. Determine the amount of inverters required for the system.
   a. According to the supplier, this system this size would typically use a 260kW inverter (see Appendix F for product data).
   b. $\text{No. of Inverters} = \frac{518.7\text{ kW}}{260\frac{\text{kW}}{\text{Inverster}}} = 1.995\text{ Inverters}$
   c. For a factor of safety, it is determined that the best option would be to use **3 inverters** to ensure that the system would function properly.
5. Determine the wire and conduit sizes of the conductors connecting the combiner boxes to the inverters.
   a. Please see Appendix F for a complete breakdown of the wire and conduit sizing.

Table 21 - Quantity take-off for DC wires

DC Wires – Combiner Boxes to Inverters				
From Combiner	To Inverter	# of Arrays	Cable Size	Conduit Size
AF01	1	10	**300**	**2"**
AF02	1	10	**4/0**	**1-1/2"**
AF03	1	10	**3/0**	**1-1/2"**
AF04	1	10	**2/0**	**1-1/4"**
AF05	1	10	**1**	**1"**
AF06	1	10	**2/0**	**1-1/4"**
AF07	1	10	**4/0**	**1-1/2"**
BF01	2	10	**300**	**2"**
BF02	2	10	**250**	**2"**
BF03	2	10	**4/0**	**1-1/2"**
BF04	2	10	**2/0**	**1-1/4"**
BF05	2	10	**1/0**	**1-1/4"**
BF06	2	10	**3/0**	**1-1/2"**
BF07	2	10	**4/0**	**1-1/2"**
CF01	3	10	**350**	**2"**
CF02	3	10	**300**	**2"**
CF03	3	10	**4/0**	**1-1/2"**
CF04	3	10	**3/0**	**1-1/2"**
CF05	3	10	**2/0**	**1-1/4"**

Constructability Analysis

Panel Weight & Mounting

As for the structural design of the system, it is lightweight and self-ballasted. Each panel weighs approximately 70 lbs (Solyndra Reveals Thin-film Solar Tubes, 2008) with a distributed rooftop load of 3.3 lbs/ ft^2 (Products, 2009). Two people can easily lift, carry, and place all the panels while one person makes the electrical connections at the array; however for a job this large it is best to have five people for installation. There are no leak-prone roof penetrations, anchoring, or ballast required to secure the system to the roof. Panels and aluminum frames are simply placed on panel mounts, allowing the panels to be placed over items less than nine inches, and then connected to each other. In comparison to traditional solar panels, the weight and mounting system of the Solyndra system is quite minimal and can be installed without having a significant effect on the existing structure. The simple installation process is depicted below in Figure 20.

Figure 20 - Installation process

Wiring

Panels are prewired for connection with each other, making the installation a fairly simple process. After the panels are mounted, the panels are connected in series and in parallel according to the given configuration. Typical wire size between panels and to the combiner box is #12 AWG. The only extra wire assembly to occur is connecting the combiner boxes to the inverters and the inverters to the panels.

Utility Connection Requirements

Since this is a significantly large system, it is highly necessary that the local utility company is notified about the installation and use of a solar energy system, as well as to determine if the utility company has any unique requirements. Notification would be sent prior to the installation and connection to the grid.

Safety

Solyndra panels, photovoltaic panels in general, are unique equipment in the sense that voltage is present whenever light is present. Therefore, power is constantly on and the panel electrical connects are live wires. It is important that all safety precautions, including local and national electric and building codes, are taken when handling and installing the panels due to the live electricity.

Schedule Analysis

The labor rate for this system with a five man crew is 15 panels/hour. Given there are 2,850 panels, the installation duration is 190 hours, which equates to **24 days** assuming eight-hour work days.

There are two key activities dates to keep in mind when installing the PV system, which are roof completion and Level 3 Commissioning start-up. According to the original schedule, the roof would have been complete by September 12, 2008 and Level 3 Commissioning would have begun in December 2008, creating an available time period of 2.5 months. Since the installation duration is 24 days, the system can be installed with minimal, if any, impact on the schedule.

Cost Analysis

Funding and State Incentives

FEDERAL

Business Energy Investment Tax Credit (ITC) (Business Energy Investment Tax Credit (ITC))

- This tax credit s is available for systems installed on or before December 31, 2016. For solar energy systems installed, the tax credit equals 30% of expenditures and there is no maximum credit limit.

STATE

Local Option Property Tax Exemption for Solar (Local Option Property Tax Exemption for Solar)

- In the state of Virginia, any residential, commercial, or industrial property with solar energy equipment can be exempt or partially exempt from any county, city, or town property taxes. Solar energy equipment is defined as equipment that is "designed and used primarily for the purpose of providing for the collection and use of incident solar energy for water heating, space heating or cooling or other application which would otherwise require a conventional source of energy."

Equipment cost

The thin-film photovoltaic system includes the following items:

Table 22 - Cost breakdown of Solyndra system

Description	Cost
System	$3,316,700
Panels (2,850)	
Wiring from Panels to Combiner Boxes	
Combiner Boxes	
Inverter	
Labor	
Monitoring System	$22,900
20-yr Warranty for Inverter/System	$62,000
Permitting	$5,000
Electrical Installation (Conduit & Labor for Combiner Box to Grid)	$320,400
TOTAL INSTALLATION COST	**$3,727,000**
Installation Cost $/W	**$7.19**
Incentives	
Business Energy Investment Tax (30%)	$1,118,100
Local Option Property Tax Exemption for Solar	$0.00
Post Incentive Installation Cost	**$2,608,900**
Installation Cost $/W	**$5.03**

**Costs obtained through discussions with Solyndra installer.*

Energy Savings

Table 23 below provides a summary of the energy savings attributed to the Solyndra photovoltaic system.

Table 23 – Solyndra energy savings calculations

PV Avg. Power Output (kWh/yr)	Electricity Cost ($/kWh)	Total Savings	Savings (lbs of CO_2/yr)
687,796	0.068	$46,770	962,914
With Future Proposed Carbon Tax			
687,796	0.1762	$121,190	962,914

- The average power output
- 1.4 lbs of CO_2/kWh (Referenced in Lori Farley's Thesis Report 2008)
- The current electricity rate, as provided by the owner, is $0.068/kWh. However, in order to show an even greater potential savings, an analysis was completed involving the proposed carbon tax on energy. The idea of the carbon tax is to place an environmental tax on carbon dioxide and greenhouse gas emissions. Implementing this tax is a means of slowing the climate change by reducing such emissions and forcing energy companies to produce cleaner energy. It is estimated that a tax between $0.1027-$0.1137/kWh will be placed on electricity produced by coal (for an average of $0.1082) (Carbon Tax, 2009).

Payback

In the case of the Solyndra system the total cost for purchasing and installing is $2,608,900 and the total savings provided by the system is $46,770. Dividing these numbers produces a payback period of **55.8 years**, which is quite unreasonable from a cost perspective for a data center.

As mentioned in the energy savings section above, it is highly probable that a carbon tax will be instituted in the near future. By implementing the carbon tax, the saving for the photovoltaic system increases to $121,190. Such a savings decreases the payback period to **21.5 years**, which is still unreasonable.

Economizers | Mechanical Influence

Research

Economizers are a type of mechanical mechanism that aid in reducing energy consumption by recycling energy produced within a system or utilizing outdoor environment temperature differences (Fontecchio, 2008). In the more recent years, economizers have become more commonly utilized within mechanical systems of data centers on either the chillers or computer room air handling units (CRAHs) due to the ability to save a substantial amount in operating costs.