Analysis of PV on a specific Federal building

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1. Introduction

This session is a synthesized analysis of installing Photovoltaic (PV) panels on the rooftop of a specific federal building - Building 5600 at ORNL (Oak Ridge National Lab). The analysis involves varies aspects from solar power generation, economic issue, type of solar panel choices, carbon footprint, storage to powering electric vehicle.

Background

The U.S. Department of Energy (DOE) Solar Energy Technologies Program, in collaboration with the Federal Energy Management Program and the National Renewable Energy Laboratory, released Procuring Solar Energy: A Guide for Federal Facility Decision Makers in October 2010. Recently, president Obama signed an executive order Thursday dictating the federal government will cut its greenhouse gas emissions 40 percent over the next decade from 2008 levels and increase the share of renewable energy in the federal government's electricity supply to 30 percent during that same period. Since the Federal Government is the single largest consumer of energy in the Nation, Federal energy saving and emissions reductions will have broad impacts. Solar energy is a good solution and it plays a significant role in the federal government's strategy for renewable and efficient energy.

Installing solar systems will help federal facilities meet the federal renewable energy requirements: 7.5% of the total electricity used by the federal government coming from renewable energy from 2013 and after. [1] Thus, we propose to install PV panels on the rooftop of federal buildings. We pick a real building for analyze: Building 5600 at ORNL as a case to analyze.

Building 5600 (35.9N, 84.3W) is the center for computational sciences at ORNL. The advantage for producing solar power on that building is that it is a shade-free roof area around Building 5600. Because if a shadow falls on a PV panel it not only reduces the output from the plant panels but also damage that part of the panel by heating up. The tilt of Building 5600's roof is flat.

2. Solar power generation

The solar power (kwh/day) generated through rooftop solar panels is calculate as:

$$P_{solar} = I \times Ar \times \eta_{eff} \times \eta_{ar} \times \mathrm{Pr} \tag{1.1}$$

Where I is daily solar radiation at building 5600 in kWh/m^2/day, (estimated from the latitude and longitude of oak ridge [2]), Ar is the estimated rooftop area, (estimated the rooftop area of Building 5600 to be 2000 m^2), η_{eff} is the efficiency of solar panel, (assumed to be 16%), η_{ar} is the area percentage utilized by solar panel and Pr is the performance ratio of the solar panel (assumed to be 75%). The result is shown in Figure 1:

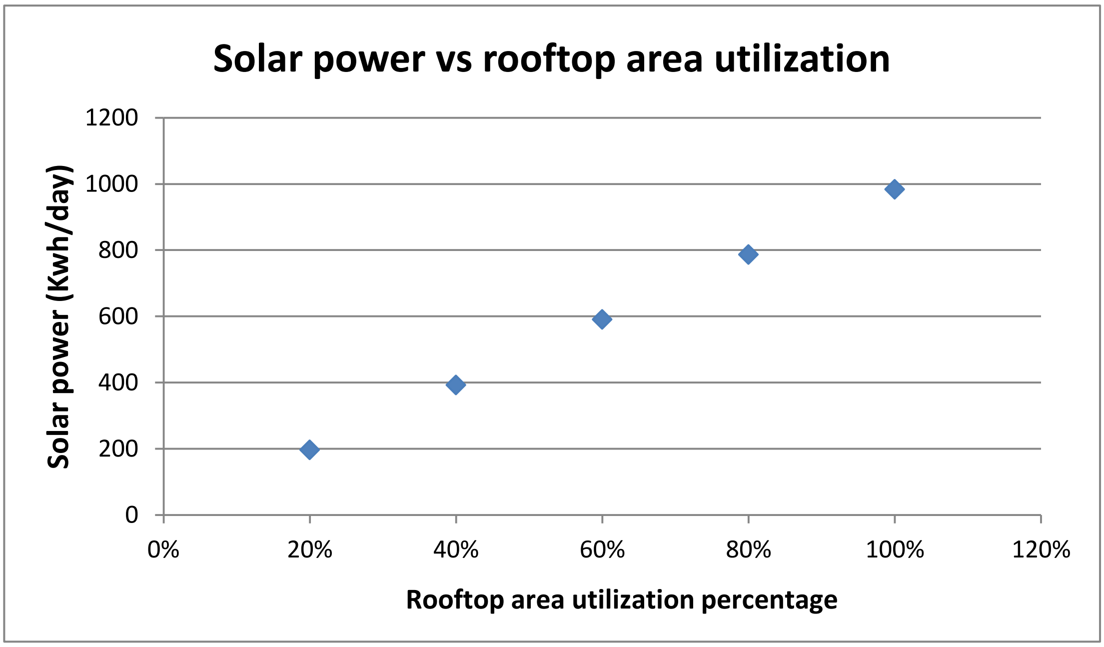

Figure 1

However, in a real building, the maximum ratio of effective rooftop area being available to utilize can be only about 80%.

3. Types of PV panel comparison

There are many types of solar panels with good performance efficiency in research environment, but only three of them are in commercial and residential use widely.

- Crystalline Silicon photovoltaics panels

Monocrystalline solar panels have the highest efficiency rates since they are made out of the highest-grade silicon. The efficiency rates of monocrystalline solar panels are typically 15-20%. [3] Monocrystalline solar panels live the longest, while they are the most expensive on the other hand.

Polycrystalline solar panels are the most commonly seen solar panels. Because of lower silicon purity, they are a little less efficient than monocrystalline panels (typically 13-16%), but also less expensive.

- Thin film photovoltaics panels

The different types of thin-film solar cells can be categorized by which photovoltaic material is deposited onto the substrate: Amorphous silicon, CdTe, CIS/CIGS. Depending on the technology, thin-film module prototypes have reached efficiencies between 7–13%. Thin-film solar panels are in general not very useful in most residential situations. They are cheap, but they also require a lot of space. Besides, thin-film solar panels tend to degrade faster than mono- and poly-crystalline solar panels

Considering the efficiency and the rooftop space of building 5600, the optimized choice is the type of crystalline silicon PV panels.

4. Economic analysis

PV systems are attractive because of their simplicity. They have no moving parts and have low maintenance requirements. DOE SunShot Initiative seeks to reduce PV system prices 75% over the 2010-2020 period. Reported system prices of residential and commercial PV systems declined 6%–7% per year, on average, from 1998–
2013, and by 12%–15% from 2012–2013. [4] In addition to the decreasing of PV module

prices, prices fell substantially for other components such as inverters (which decreased by 15% to 18%) and racking systems (19% to 24%) in the past several years. The Figure 2 illustrates the PV facility by cost component. [5]

According to Figure 3, a full-year blended average cost for non-residential PV rooftop system is $2.36/Wdc, which represents a 20 percent decrease year-over-year. [6] The non-residential market has proven much harder to scale, and has been much more sensitive to incentive reduction, than the residential market. But we are confident about the growth of non-residential, especially the federal market, because many states are poised to have stronger years in the future.

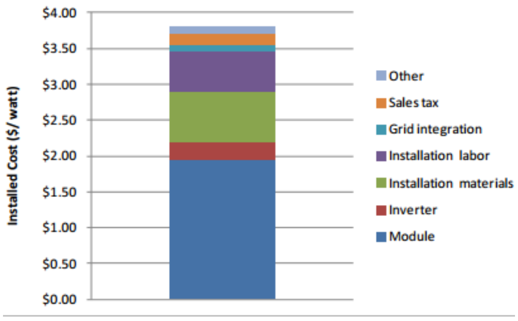

Figure 2

Figure 3

Taking 80% rooftop area utilized of building 5600 as an example, the installation cost is about 256,000 dollars. Total operation and maintenance (O&M) cost of fixed-tilt c-Si solar cell is $47/kw·y.[7] Average retail electricity price to ultimate customers by end-use sector in Tennessee is 9.20 (cents per Kwh) in 2014. [8] Thus, the annual electricity cost saving is 26,427 dollars. Taking into consideration of O&M cost, it will take more than 12 years to earn the investment back. Other rooftop coverage ratio costs are shown in Table 1.

The warranty of c-Si PV panels mostly is 25 years, so if the payback period is around 12 years, it is a worth investment on building 5600.

Rooftop area utilization	20%	40%	60%	80%	100%
Solar Power (Kwh/day)	197	393	591	787	985
Installed Cost (thousand $)	58	116	174	256	290
Carbon Saving (Kg/day)	26	51	77	102	128

Table 1

5. Carbon emission saving

Buildings are responsible for 36% of U.S. emissions of carbon dioxide produced by human activities. We have an opportunity to cut our energy consumption and carbon emissions significantly through use of energy-efficient technologies. As is common nationwide, ORNL's greatest source of green house gas (GHG) emissions is a result of purchased electricity. Thus, we do the calculation about how much carbon emission can be reduced by the PV panels on building 5600.

Lifecycle GHG Emissions of Mono-Crystalline Silicon (m-Si) and Poly-Crystalline Silicon (p-Si) are ranging from 30~220 g CO_2 eq /kWh and from 15~220 g CO_2 eq /kWh. We pick the average median value 65 g CO_2 eq /kWh in the calculation. [9] Carbon intensity of the energy supply in Tennessee is 54.2 kg CO_2 eq /million BTU [10], which is equal to 185 g CO_2 eq /kWh. Carbon emission saving is:

$$C_{save} = E_{solar} \times (C_{TN} - C_{solar}) \qquad (1.2)$$

Taking 80% rooftop area utilized of building 5600 as an example, 102kg of the carbon emission reduced by this building every day. Carbon saving of other rooftop coverage ratios is shown in Table 1.

Apart from its benefits in GHG reduction, the use of solar energy can reduce the release of pollutants—such as particulates and noxious gases—from the older fossil fuel plants that it replaces.

6. Storage system choice

PV panels produce intermittent power, so the storage system is necessary for integrating energy created during the day and allowing of usage during the night. There are many forms of renewable energy storage: rechargeable battery, thermal energy storage, compressed air energy storage and supercapacitors.

The PV capacity required by building 5600 is 787 kwh/day (assuming the 80% roof top coverage case). Based on the most economic storage mechanism, building 5600, whose capacity is in the range of 10^2 to 10^3, should choose thermal storage system as the method of energy storage.

7. Solar power for Electric Vehicle

Solar Power and Electric Vehicle chargers are the key to significantly reduce our dependence on fossil fuels and are the natural evolution of our energy infrastructure. Coupling this two together, plug-in EV with solar power is a beneficial method.

Taking 80% rooftop area utilized of building 5600 as an example, it generates 787 kwh electricity everyday. The energy consumption of Nissan Leaf and Tesla are 29 kwh/ 100 miles and 38 kwh/100 miles separately. The battery of 2015 Nissan Leaf is 24 kWh 360 V lithium-ion battery, while Tesla Model S equipped with an 85 kWh battery pack. Thus, the total solar energy gathered by building 5600 can fully charge 32 Nissan Leaf cars or 7 Tesla cars per day.

8. Conclusion

From a specific federal building, we see a variety of advantages for PV panels installation on the rooftop: reducing GHG emission, saving electricity cost in a long term and supporting electric vehicle in ORNL. Moreover, we do an optimized recommendation of choosing crystal silicon PV panels and thermal storage system for building 5600.

Federal government might consider to picking several federal buildings like building 5600 and practice the rooftop solar panels in reality. With the development of technology and the growth of PV market, the cost would be decrease while the efficiency would be improved in the future.

Reference:

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