Application of photovoltaic's in the building and construction industry as a power generating facility

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Abstract *This Article was prepared for The Specialists Trade Alliance of Singapore. It presents a summary of regulations and rules of thumb for the implementation of solar energy systems within a building facility, and information on recent legal precedents for financing such systems. An example of a solar energy system employed to meet a fraction of a building facilities power is presented.*

Introduction

Solar energy is a mature technology which has reached cost or price parity with conventional power generation sources in certain jurisdictions. Solar energy is expected to grow in the near term to help meet the worlds rising demand for energy [1]. Photovoltaic solar cells are semiconductor devices which convert light into an electrical voltage and current at their electrodes [2]. These components are assembled within a solar module comprised of glass, laminate, a back sheet, and a frame. All-glass type solar modules are available, and these may serve as a building panel material. Solar modules output DC power, and in combination with an inverter produce AC power to match any common electrical standard. These electrical devices may be used within a building facility to supply it with electricity. Solar panels are installed onto a building rooftop, whereas installation on a building façade generates roughly 30% of what can be obtained from a roof installation.

Typically, a solar energy system may produce energy for more than 20 years due to the durability of photovoltaic modules [2]. The future energy prices achieved from these systems are derived directly from the capital expenditures incurred upon installation of the solar power system, and not directly the price of combustible fuels. Thus, installation of a solar power system may be used as a hedge of future energy costs. Financing solar energy systems may allow an electricity user to achieve a competitive energy price.

Additional benefits of using photovoltaic modules within a building facility include the removal of costs associated with alternate building materials when solar panels are used to replace them, the decrease in a buildings temperature and subsequent cooling load due to additional roof insulation [3], and an increase in the lifespan of a building rooftop by decreased thermal wear.

Compliance and certification

Compliance for the installation of solar energy systems in Singapore is stipulated under the Electricity Act of Singapore (Chapter 89A), and Section 612 of the Singapore Standard CP5 Code of Practice for Electrical Installations. The interconnection compliance under the Transmission Code and Metering Code requires filing an application through SPPG when a solar electricity system and grid connection intersects (as is common when not all a buildings energy demand is derived from the solar system). Licensing for the use of >45 kVA non-residential electrical systems must be filed through the Energy Markets Authority (EMA). In particular, photovoltaic solar panels used in a system should be certified under the IEC standards IEC61215 and IEC60439-1, or equivalent. More information on compliance may be found in the *Handbook for Photovoltaic (PV) Solar Systems* published by the Energy Market Authority (EMA) of Singapore [4].

Financing and Legal Precedents

The solar leasing concept which is derived from a purchase power agreement (PPA) has notably grown as a business methodology recently. Solar leasing is becoming a mainstream option for financing PV systems. For example, in the USA and Germany Solar City Corp, which is planning an IPO, has installed solar PV systems under the solar leasing scheme on 33,792 buildings as of July 2012. The essential feature of a solar lease model is to bill the electricity user for the power delivered to them, while the capital expenses and maintenance costs are the responsibility of the solar energy installer or system integrator. Companies like Credit Suisse, U.S. Bancorp, Google and utility PG&E have put a cumulative $1.57 billion into 23 funds to finance solar leases today. These US-based investors were no doubt drawn to the 30% federal investment tax credit for solar systems. As is generally the case worldwide, solar installations are most viable in places where financial incentives are available, or electricity prices are considered high.

The activities of companies developing financing arrangements for solar power systems have established the legal precedents for solar leasing arrangements. There are a variety of methods through which solar systems are financed. Solar leasing schemes generally provide for a user to make electricity purchases through a private contractual agreement. The system installed may be financed through a single private entity or individual, or sometimes the systems may be financed through a pool or membership agreeing on a fixed term bond. Leasing price terms will generally be contracted within either of a *floating* price mechanism where a public benchmark price derived from an alternative means of acquiring electricity, such as an electricity grid, are published and transacted; or a *fixed* price mechanism by which the price of electricity delivered from the solar power generator is calculated using a fixed price or an escalator price derived over the period of time agreed on the lease. Leases may also be subject to a partial upfront payment.

In Singapore, solar PV system leasing is in its infancy. The Singapore government's Housing & Development board (HDB) has pioneered the industry by offering a MW-scale leasing tender for its residential estate at Punggol. Energy prices achieved through solar leasing of such systems are commensurate with current grid electricity purchase prices within Singapore [5], thus further activity in the Singapore market may be expected going forward.

Construction and Components

An example of a clamp based mounting system is shown below. The system causes no holes or punctures to the roofing material. In this instance the additional loading is less than 200 N / m^2. The system is comprised of an array or arrays of photovoltaic panels strung using solar grade DC cables and connected through an inverter. Balanced modules strings are usually employed along with a distributed inverter arrangement. Central inverter arrangements may however be employed when localized cabling and low shading losses can be achieved. A bidirectional meter is connected to the solar power system and the grid distribution board to monitor power used. Surge arrestors are installed at least on the DC bus.

Fig. 1 shows a typical scenario of a building connected solar electricity system. The solar energy is connected through the inverter(s) and distribution board to the building load, while additional electricity may be purchased through the grid. Fig. 2 shows a rooftop installation using and interference clamp mechanism for mounting the solar panels, which causes no holes or punctures to the sheet material on the rooftop. Fig. 3 is a thermal image demonstrating the cooling effect of the solar panels due to the increased insulation, which in turn reduces the cooling load demand of the building facility.

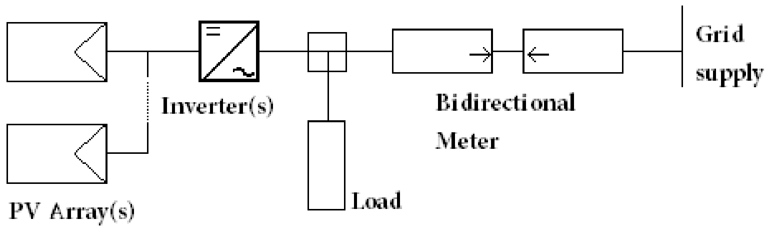

Fig. 1: Electrical system configuration layout. The PV arrays interface DC to AC inverters. A bidirectional meter monitors power input from the grid and solar power output to the grid.

Fig. 2: A mounting clamp system shown for installation of solar panels on the roof structure. Various methods of mounting are available, including struts and interference clamps which cause no holes or punctures to a rooftop. Easements and clearance for other gear installed on a roof are made by removing panels from the module array. An example of an interference fit clamp is shown in the right.

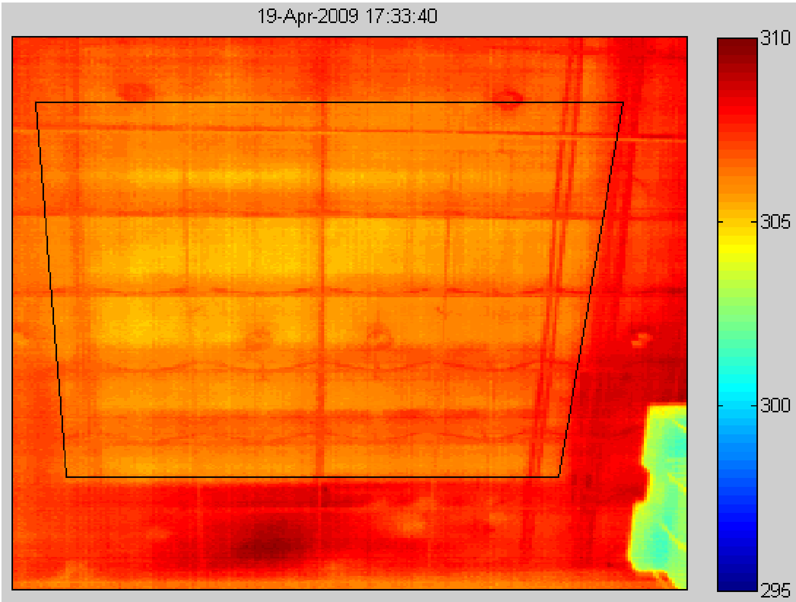

Fig 3: Thermal image of a rooftop showing a reduced temperature of the building roof within the demarcated region above which solar panels act to insulate the roof from heat from the sun. A nominal difference of approximately 4 degrees was observed during daytime. Complements of Jan Kleissl, University of California San Diego.

Capacity Calculations

Calculations of system capacity are straight forward, however incorporating shading figures and multi axis tilting, if used, may require a more complex analysis [6, 7]. Here it is assumed that polycrystalline silicon type photovoltaic modules are used with an efficiency of approximately 15%. The available rooftop space must be determined. To provide for proper easement around the system components, a rule of thumb is to multiply the total available area by 0.12 to obtain the peak output of the polycrystalline silicon solar system (around noon). Alternatively, the panel layout design should be completed and the number of installed modules must be multiplied by their output. This is will yield the peak output of the solar system. In Singapore, the available solar irradiance translates into approximately 1200 effective hours of sunlight per annum [4]. The total annual energy generated from the system will be

$E = 1250$ [h] x 0.12 [W/m^2] x (total area [m^2]) = 1250 [h] x (# modules) x (peak output [W]).

System Example

The estimated load demand of typical commercial real estate [8], the local available solar irradiance, and system capacity for a large roof area was used to simulate the performance of the solar energy system below:

System type	Grid connected rooftop solar power system
Latitude	1.3667° N
Longitude	103.7500° E
Local effective sun-hours	~1250 h / annum
Construction Timeline	4-6 months

Peak Power Capacity	905.4 kW annually
Energy Capacity	1131 MWh annually
Total Area	7540 m^2
Peak demand	434.5 MWh, monthly
Off Peak demand	46 MWh, monthly
Solar fraction	21%

Fig. 4 shows comparative daily variations in grid electricity purchases and solar power delivered against the load demand of the building facility. On some days limited solar power output may occur due to shading of the system by cloud cover, whereas other periods show a peak in output around noon and a corresponding reduction in the grid purchases required to meet the load demand. Fig. 5 shows the monthly solar fraction of power over a single year, while Fig. 6 shows the solar power delivered through the inverters to the building load on an hourly basis over a single year. For this case, an average solar fraction of 21% is obtained through the balanced performance of the solar energy system.

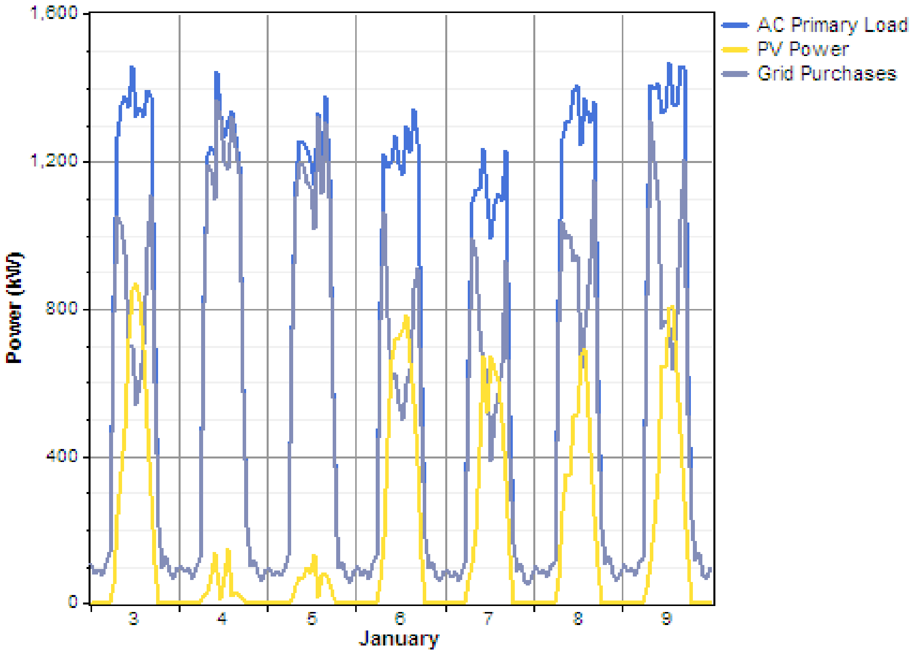

Fig. 4: Exemplar daily variations in load demand, grid purchases and PV power delivered based on the hypothetical example given within. The PV system capacity was 905 kW and the cumulative on and off peak load demand was 485 MWh monthly. Illustration shows the scale of PV power to grid power purchases against the building load demand.

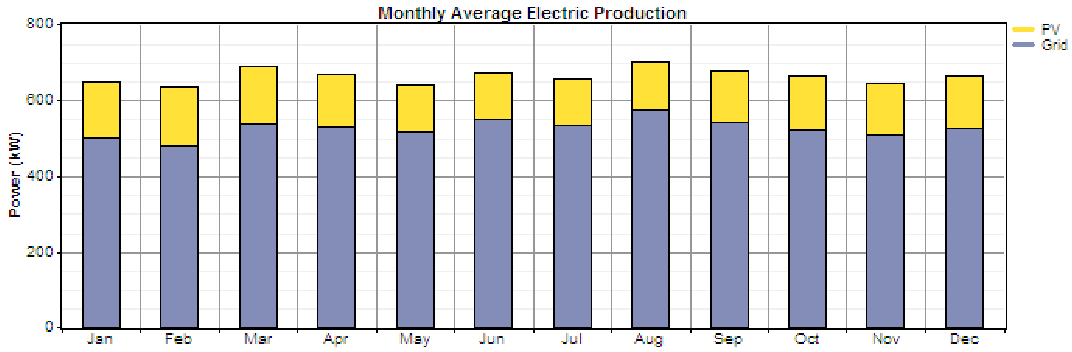

Fig. 5: Comparative annual fraction of energy delivered to the load through photovoltaic power (yellow) and from grid purchases (blue).

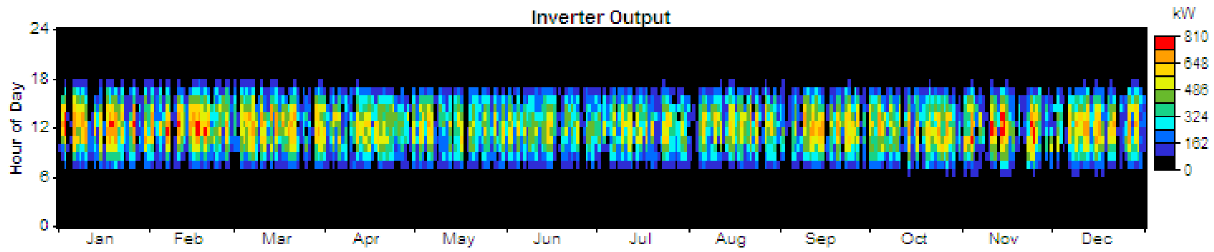

Fig. 6: Simulated system output at the system distributed inverters based on the nominal solar system peak capacity.

Combining the installation of such power generation systems along with the replacement or upgrade of other building components such as efficient lighting or air-conditioning units may grant an economically feasible solution to decrease the cost of energy used within a building facility.

Conclusion

Installing photovoltaic power generation systems within a building facility may provide a portion of a typical buildings energy demand. The legal precedent for financing or leasing of electricity through the installation of such systems has been established through means including private solar leasing schemes and various forms of purchase power agreements. The implementation of photovoltaic components in the construction and engineering industry along with financing arrangements for such energy systems may provide a framework to establish solar power systems for affordable generation of a fraction of the energy demand within Singapore.

Acknowledgements

Thanks to Jan Kleissl and Daniel Rosa for contributing data to the article, including the thermal image and market research data.

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