CONSTRUCTION OF TWO 25M TALL VERTICAL ARRAYS WITH 2ND GENERATION AMORPHOUS SILICON PHOTOVOLTAIC TECHNOLOGIES

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ABSTRACT: The University of Hong Kong PV research group (PVHKU) is developing a series of related PV research to promote PV applications in the region. A building integrated photovoltaic (BIPV) array of 25M tall with total area $92m^2$ consisting of two types of second-generation thin-film technology was built onto an existing HKU building by October 2000. The purpose of the array is to simulate typical Hong Kong façade, which are generally higher than 120M. We aimed at unitized construction for fast erection and quality-controlled prefabrication. Array and inverter efficiency evaluation will be conducted and data of solar radiation, array power output, inverter efficiency, panel temperature, etc were collected and monitored. Monitored data will be published to compare the two types of 2nd generation amorphous Silicon arrays with very similar construction.
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1. INTRODUCTION

In modern urban areas, curtain glass walling is the popular choice of developers of commercial buildings. One of the reasons is its high-tech and prestigious image. In practice, it is not necessary for all of these glass panels to be transparent. For each floor, usually at least 25% of the glass panels can be of opaque type, typically, these are the areas above the false ceiling and below the raised floor of the next floor. For some buildings, it may need only half of the effective height be covered by transparent glasses, then the total area for opaque panels can be more than half of the total surface area of the vertical exterior walls.

Renewable energy sources are hopes for sustainable development of our society. One major candidate of renewable energy sources is solar energy, which is clean and readily available. Traditionally, solar energy has been used to quite a large extents in remote areas, such as powering telecommunication equipment on hill tops, lighting towers on sea shores, and even all the equipment on satellites. However, solar energy can also be applied in urban areas effectively if the above-mentioned opaque glass panels on commercial buildings could be replaced by photovoltaic (PV) panels. These panels convert the solar energy directly into electrical energy and can support part of the electrical loads in the building. Such a concept is called building integrated photovoltaic (BIPV) system.

For a grid-connected BIPV system, the DC electricity generated from PV panels will be converted to AC by an inverter and fed to the normal electricity distribution network of the building. Effectively, for every electrical load in the building, it is partly fed from the PV panel and partly from the normal grid. The relative percentage depends on the yield of the PV panels (hence it's depend on the weather situation). The concept is not to expect the solar energy to support all the electric load(s), and not even part of the electric load(s) on a full time basis. Solar energy is only a supplement to the grid electrical energy (or the other way round). Therefore the battery set can be completely eliminated.

In addition to the avoidance of the conventional obstacles in application of PV panels, grid-connected BIPV has one further merit when it is applied to commercial buildings of tropical or sub-tropical areas. In these buildings, the major portion of the consumed electrical energy is for the air-conditioning plant, hence the peak electricity demand will occur at about noon or early afternoon time in summer. This peak time obviously matches with the timing of peak electricity generated from the BIPV system (Figure 1). Therefore, the BIPV system does not only cut down the total electricity energy drawn from the grid, but also cuts down the peak kVA demand electrical power [1].

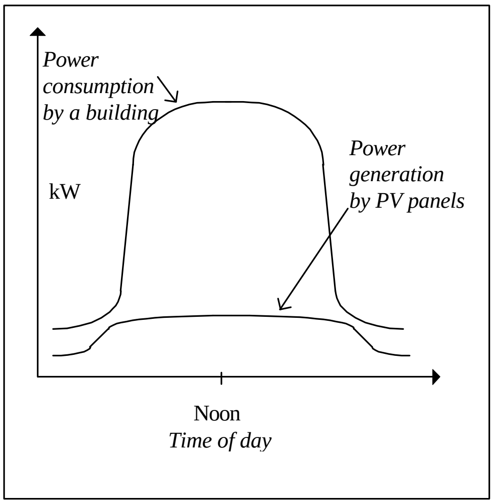

Figure 1. Consumption profile

The University of Hong Kong (HKU), PV research team has been formed since 1997. Currently we are developing a series of related PV research project to promote PV applications in the region.

A major project is the installation of PV panels onto the west facade of an existing building within the HKU campus, forming two almost identical arrays. The supporting frame is a steel structure of 25m tall vertical arrays by 4m wide, with a total panel area of 92m^2. Two types of second-generation amorphous Silicon technologies, namely the PST/ASE (from Germany) and EPV (from USA) were installed on the frame simulating typical Hong Kong façade. The array was constructed 10 degrees offset from the wall towards South to capture more solar radiation.

From experiments done on a small test rig in HKU with PV panels mounted vertically on NE, SE, SW and NW directions respectively, we found that the SW direction received most solar radiation amongst the four directions. However, construction of the arrays has to suit for constraints of existing buildings, and therefore the PV systems were installed on the west facing façade of that building. It is estimated that the peak power capacity shall be 4.3 kW, while the annual yield will be about 3,000 kWhr. The construction is shown in Figure 2.

Figure 2. The constructed PV façade in HKU

This project is used as a platform to study the real performance of grid-connected PV system in Hong Kong environment, its detailed electrical specifications, the architecture and structural design issues, the unitized construction [2] for fast-track erection and quality controlled prefabrication with interior maintenance access. This paper will concentrate on the electrical aspects of the system.

2. SYSTEM DESCRIPTION

The electrical subsystem of the grid-connected PV arrays comprise mainly of the following aspects:

2.1 PV panels

Three PV panels were connected in series forming a string and strings connected in parallel to form the whole array. The selection of voltage level of the DC link is very important. A higher DC voltage can reduce the wire copper loss and increase the efficiency of the inverter, but may imply higher chance of electric shock. The optimal DC voltage depends on local wiring regulations. In Hong Kong situation, a 200V D.C. link voltage would be a suitable choice for small BIPV systems. More detailed research needed for this parameter.

Table I: Characteristics of PV panels at STC

	PST/ASE panel	EPV panel
Model	PM6008A36N Opak	EPV40
Supplier	ASE GmbH, Germany (now known as RWE Solar GmbH)	Energy Photovoltaics, USA
Dimension	1000mm X 670mm	1250mm X 640mm
Ppeak	40W	40W
Voc	50.2V	62.2V
Vpeak	40.6V	44.8V
Isc	1.18A	1.16A
Ipeak	0.99A	0.9A

2.2 Power conversion subsystems

The two arrays are separately connected to a centralised grid-connected inverter from Solwex and Omnion respectively for power conversion and conditioning before feeding the power into the grid. The details for the power conversion subsystem (PCS) is as follow:

Table II: Characteristics of the two PCS

	PST/ASE array	EPV array
Inverter model	Solwex 3090	Ominion 2400-34151-00
Supplier	Solwex Vertriebsgesellschaft mbH, Germany	Omnion Power Engineering Corporation, USA
DC input	Unipolar	Bipolar
Peak Power	3000W	3300W
Max. Voc	160V DC	± 300V DC
MPP-tracking	85 – 120 VDC	± 100 - 300V DC
Imax	15A DC	18A DC

3. ARRAY PERFORMANCE

The DC output current, voltage, and power from the arrays together with the solar radiation onto the same plane are continuously being logged by a data acquisition (DAQ) system. Also, the monitored data can be reviewed real-time through the internet. The URLs are:

http://147.8.174.47/PSTpower.htm
http://147.8.174.47/EPVpower.htm

The power and array efficiencies on a partial sunny day (24th Agust 2001) is shown below:

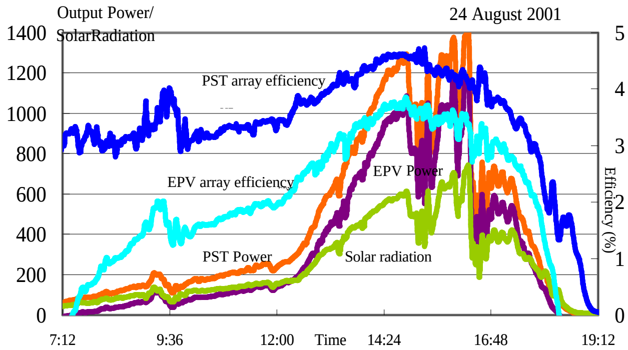

Figure 3. Array performance on 24 August 2001

On 24th August 2001, the solar radiation onto the vertical plane was at maximum 763 W/m^2. Peak power of the arrays were 1570W (PST) and 1318W (EPV) respectively. Their maximum array efficiencies were 5.23% (PST) and 4.25% (EPV) at solar radiation of 507 and 519 W/m^2. The maximum panel temperature recorded that day was 55.2ºC at about the time of peak solar radiation. The average array efficiencies were less than the PV rated efficiencies at Standard Test Conditions (STC), because the whole array behave very differently to an individual panel operating under the laboratory conditions of STC. One of the critical factor in subtropical region is the temperature of the panels. When the air temperature is around 30ºC, and the sun is shining bright (above 500 W/m^2 onto the vertical plane), the panels can be heated up to above 50ºC. Since our construction is an open, ventilated support system, we would expect an even higher panel temperature in other BIPV systems in such a sub-tropical climate as Hong Kong.

4. EFFICIENCY COMPARISON

We compare the array efficiencies at different solar intensity to study the system performance as below:

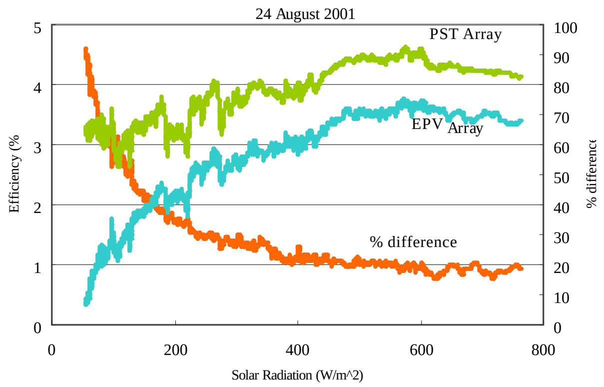

Figure 4. Efficiency comparison

The difference in array performance is obvious when we compared the average array efficiencies at different solar intensity. The averaged peak array efficiency of PST array was 4.6% whereas that for EPV array was 3.8% at solar radiation of 620 W/m^2. The percentage difference was about 20% to 30% at a medium solar radiation range (above 250 W/m^2) and became steady above 600 W/m^2. This differnce is larger than the difference of the nominal panel efficiencies at STC, implying that the array performance depends on various factors and the panel efficiency is only of indicative values. And the difference is even exceptionally large in the lower radiation end. It could be up to above 90% (as 3.4% versus 0.3%). This could possibly be due to the ineffectiveness of Omnion inverter in mamimum power point tracking in that range of power input.

5. ENERGY YIELD

We installed a kWhr meter for each of the PV system to record the energy yield. This helps in reviewing the estimation of the anuual energy yield of the arrays and long term monitoring of the systems. The recorded energy yields during this summer are shown in Table 3.

Table III: Energy yield of PV arrays

Period	PST Array output	EPV Array output	% difference
April 2001	61.2kWhr	39.5kWhr	35.5%
May 2001	101.8kWhr	65.3kWhr	35.9%
June 2001	82.7kWhr	50.1kWhr	39.4%
July 2001	91.8kWhr	56.0kWhr	39.0%
August 2001	99.4kWhr	65.9kWhr	33.7%

The energy yield from the EPV array was significantly less than our estimation. One of the main reasons was the consumption of energy by the Omnion inverter during stand-by mode. We observed that the difference in kWhr meter before and after the inverter stand-by for the whole night could be 0.25kWhr. This is consistent with the information from the supplier that the inverter consumes up to 15W during stand-by mode and thus consuming: 15W x 3600s x 16hr (16 hours of stand-by) = 0.24kWhr. This amounts to the energy yield from the EPV array on a cloudy day! This is particular considerable to our installation because it is a vertical array and hence the inverter stand-by mode is expected to be longer than that of systems on a horizontal plane.

The cumulative energy for the period 2nd April to 2nd September (totally 5 months) showed that PST array generated 36.7% more energy through the inverter. This is a significant amount of difference when we consider that the PV panels are only of 16% difference in efficiencies at STC. If we deduct the power consumption of Omnion inverter at 0.24 kWhr per night, the difference would still be 26.6%. This indicates that the EPV array is performing unsatisfactorily, partly due to its poor efficiency at low solar intensity range.

6. ANNUAL YIELD ESTIMATION

Due to the consumption of energy by the inverter connected to the EPV array, we would concentrate here only the discussions on annual yield of PST array. From the kWhr meter we found that the PST array generated 436.9kWhr for a continuous operation of 2nd April to 2nd September 2001. This is 27.3% of the annual yield we estimated for the PST array. Although from the record of the solar radiation and the weather reportfrom the Hong Kong Observatory, we had in average 6.8% solar radiation less than a Typical Meterological Year (TMY) for April to August 2001, this recorded energy output of the PST array is still lower than our estimation.

Our initial estimation of the total array output of 3,000kWhr was based on efficiency of the module at Standard Test Conditions. It should be appreciated that these conditions refer to a rating based on performance under laboratory conditions. It is now widely recognized in the industry that these ratings do not provide an accurate guide to performance under real operating conditions when temperature, air mass and solar radiation vary considerably from those standard conditions of 25ºC operating temperature, air mass of 1.5 and solar radiation of 1000 watts/m^2. In addition there is the power loss from the cables and connections. Generally described as the Balance of Systems, it depends on the system design and inverter quality, and might vary from 90-96% efficiency. All these factors had to be taken in to consideration for a more accurate annual estimation.

7. CONCLUSIONS

The two arrays are performing quite differently although they are of the same area, location, and technology with similar rating claimed. One of the purposes of this research is to work on a comparative study on the two 2nd-generation thin-film technologies. Their differences in various aspects are summarized as follow:

Table IV: Comparison of PST and EPV array

Issue	EPV Array	PST Array	Percentage difference
Material cost (Modules + inverters + freight charges) Note: cabling + components excl	HK$ 110,782	HK$ 121,618	9.78%
Array peak power recorded	1524W	1761W	13.5%
Averaged Array peak efficiency	3.7%	4.5%	17.8%
Array peak efficiency	5.5%	6.8%	19.1%
Energy yield after the inverter (2nd April to 2nd Sept)	276.8kWhr	436.9kWhr	36.7%

Generally speaking the PST array is performing about 18% better in term of power output, and 37% better in terms of energy output. The dissimilarity of power output was larger in low solar radiation situation. This could be due to the inefficient maximum power point (MPP) tracking of the Omnion inverter at low power end (less than 10% of rated power). However, a large portion of the difference in energy output was due to the energy consumption of the Omnion inverter during the stand-by mode, with an estimated 0.24kWhr consumed every single night. If we neglect the energy consumed during cloudy/rainy days by the Omnion inverter, we would expect that the difference in energy output for the two systems would be about 26.9% cummulatively under various solar radiation. This is still larger than the difference of the PV module efficiencies at STC, implying a signicance of the influence of other system components on the overall system efficiency.

The above findings support further our conclusion that at the system level, the efficiency of the panel is only part of the story. There are many other aspects and factors in determining the overall efficiency of the system. Amongst which, the system design (e.g. the choice of operating voltage of DC sub-system) and the specification of parameters of the inverter are of critical importance to the system performance. An inverter that consumes as much as 15W during stand-by mode can tremendously affects the long-term performance of the system.

Our comparative performance data collection indicates also that similar technologies (amorphous silicon, tandem junction, second generation) do not necessarily perform equally. In highly variable weather conditions, the response and performance under lower solar radiation conditions is as significant to the total annual energy output as the performance under the peak solar conditions. Weather/solar radiation pattern and choice of module is thus critically related. It is unusual to make a large-scale comparative performance analysis and it highlights response not normally identified in sales literature or product specification details.

For the Tropical or Subtropical weather conditions like that of Hong Kong, the panel temperature can be much higher than 25ºC, the temperature at STC. Hence another important factor in considering the PV module to be installed would be its temperature coefficient (the rate of power decrease with increase in module temperature). Also, a well-ventilated design for the supporting frame would be needed in such a weather condition.

In the course of our system design, the limitation of a vertical PV façade was well addressed and expected. We chose to install the testing array on a vertical plane to suit the high-rise context in Hong Kong, where about a 50:1 wall to roof ratio was recorded. We therefore have seen the potential of the vertical facade to generate electricity while also functioning as the building skin, and thus achieving the “added-value” for installing PV compared with solar control glass or other façade material. Nothwithstanding these, careful system design would be crucial to the overall system efficiency.

8. ACKNOWLEDGEMENT

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9. REFERENCE

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