USE OF SOLAR ENERGY TECHNOLOGY IN AN URBAN CITY ENVIRONMENT

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Abstract

Electrical and Mechanical Services Department of the Government of the Hong Kong SAR commissioned a consultancy study in November 2000 to assess the feasibility and potential for wider application of renewable energy in Hong Kong. A pilot project to install a Building Integrated Photovoltaic system at Wanchai Tower is also included as part of the renewable energy study.

This paper gives a brief account of the experience gained from the deployment of a photovoltaic system in an existing high-rise government building situated in the densely populated business district of Hong Kong.

Keywords

Renewable Energy, Photovoltaic Panel, Building Construction, Grid Connection, Urban City

1. Introduction

As we all know, Hong Kong has no indigenous energy resources. Hong Kong, in fact is a net energy importer, and is susceptible to changes in the global energy market. Against this background, Hong Kong's energy policy is to maintain a reliable and safe energy supplies at reasonable prices to sustain our economic development. At the same time, the SAR Government is also needed to facilitate the development of the energy sector, safeguard the interests of the consumers as well as to protect the environment of Hong Kong.

In November 2000, Electrical and Mechanical Services Department (EMSD) of the Government of the Hong Kong SAR commissioned a 2-stage consultancy study to investigate the viability of using new and renewable energy technologies in Hong Kong. The consultancy study will be concluded in early 2004.

The Stage 1 Study evaluates the potential of various forms of new and renewable energy for wide-scale local use; and identifies a number of associated legal, institutional and promotional issues. It also makes recommendations for formulating an implementation strategy.

The Stage 2 Study is a design-and-build pilot project involving the installation of Building Integrated Photovoltaic (BIPV) system at Wanchai Tower, which is a high-rise government office building located in a busy commercial district. The installation works commenced in late April 2002 and was completed in end 2002. The performance of the BIPV system will be monitored by EMSD until early 2004.

2. Thinking Behind the Project

Hong Kong has an annual average global horizontal solar radiation of 1.29 MWh/m^2, and is regarded mildly rich in solar energy resource. EMSD considers that the stable and abundant supply of sunshine throughout the year and the large number of high-rise buildings in Hong Kong can provide an environment favourable for studying the feasibility of using BIPV systems. Hence, a BIPV pilot project is included as the second stage of the consultancy study. At the same time, the pilot project can also serve as a demonstration to promote public awareness on the potential use of solar power.

2.1. Site Selection

The objectives of the pilot BIPV project are as follows:

a) To gain experience on the operation and maintenance of a BIPV system under typical local conditions, and to collect and analyse the technical data from the project; and
b) To look into the practicable application of BIPV in a commercial building in Hong Kong.

A multi-criteria methodology was adopted in 2001 to identify the most suitable government building for installing the pilot BIPV system. Factors considered were the building type, location, height, orientation, public exposure, solar access, and other site-specific issues. Among various government buildings, the Wanchai Tower was selected for the pilot project.

Wanchai Tower is an existing high-rise government building located in Wanchai District, which is one of the busiest areas in terms of traffic and pedestrians flow in Hong Kong. The orientation of the Wanchai Tower is 5 degrees from the true South, and the south façade of the building faces the Gloucester Road. Two other high-rise buildings namely Revenue Tower and Immigration Tower surround the front yard of the building.

2.2. Design Considerations

Photovoltaic (PV) system is highly regarded as a potential RE technology for application in the densely populated urban areas of Hong Kong. It emits no pollutants, no radioactive substances and no noise. Among all the potential sites for installing BIPV system, commercial buildings are considered a reasonable and sensible choice.

In Hong Kong, the peak electrical load of a commercial building normally occurs during a hot summer afternoon, and at the same time, the BIPV systems are also giving out its maximum power output. Hence, it can help to reduce the maximum electrical demand of the building. In addition, when BIPV system is installed, any loss of transmission and distribution of power will no longer be significant since the power is generated within the boundary of the building itself.

The main design considerations of the pilot project are summarized as follows:

a) Conversion efficiency of mono- and poly-crystalline silicon PV cells;
b) Shading effect of the surrounding buildings;
c) Optimum tilting angle of PV panels on the roof;
d) Aesthetic effect of PV panels on facades;
e) Reduction of solar heat gain while maintaining adequate daylight penetration for the sunshade and skylight PV panels;
f) Reduction of peak demand for the mains supply; and
g) Reliability, stability and power quality of grid.

2.3. Photovoltaic Technologies

The PV panel, which is the main component of the photoelectric generation system, consists of a group of PV cells connected in series to give a nominal output voltage and current. There are 3 common commercially available types of PV cells, namely, mono-crystalline silicon, poly-crystalline silicon and non-crystalline (or amorphous silicon) thin-film. The conversion efficiencies from solar energy to electricity of these PV cells range from 7% to 19% under standard testing conditions. Since both mono-crystalline and poly-crystalline silicon cells have higher conversion efficiencies than thin-film amorphous, they are selected for use in this demonstration project. Figures 1 and 2 show the poly-crystalline and mono-crystalline silicon PV cells.

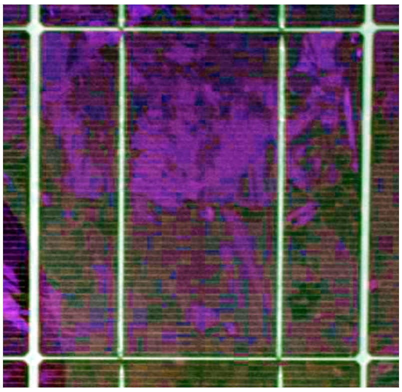


Figure 1: 130x130 mm poly-crystalline Si PV cell

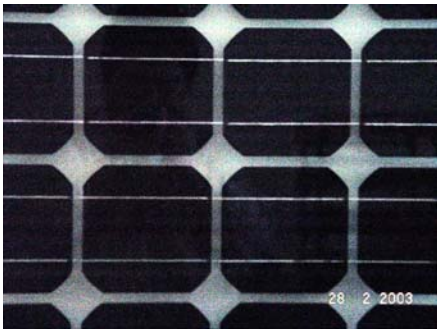


Figure 2: 130x130 mm mono-crystalline Si PV cell

3. BIPV Installation at Wanchai Tower

Three types of BIPV sub-systems are installed at Wanchai Tower, which cover a total area of 500 m^2 with a peak power output of 55 kW and they are:

a) Rack type on the roof top;
b) Sunshade type from 1^{st} to 12^{th} floors; and
c) Skylight type at the front entrance hall.

3.1 Rack type

The “Rack” type sub-system is installed on the rooftop of the building (Figure 3). It consists of about

160 m^2 of poly-crystalline silicon PV panels with a total peak power of 20 kW. A computer software known as "Array Shading Evaluation Tool" together with the fisheye photographic technique has been used for the analysis of the shadowing effects from adjacent buildings. The PV panels are tilted optimally at 10^o to the horizontal plane after considering the shading effect due to adjacent buildings.

Figure 3: Rack Sub-system

3.2 Sunshade type

The second sub-system is called the "Sunshade Screen" sub-system which comprises double-glazed panels completed with integrated mono-crystalline PV cells. The panels each rated at 76.8 W (peak) are externally mounted on the building facade to provide shading for the upper portion of all south-facing windows from 1st to 12th floor of the building (Figures 4 & 5). The total area of panels installed is about 230 m^2 and the total installed peak power is 25 kW. Apart from generating electricity, the sunshade type PV panels can also reduce the solar heat entering the building through the windows.

Figure 4: Sunshade Sub-system – Interior View

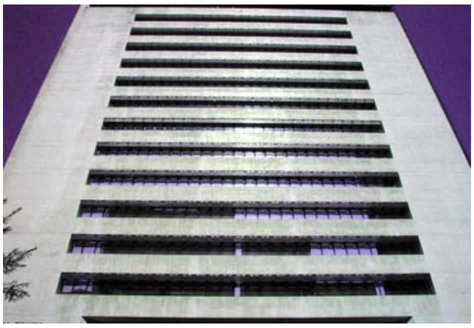


Figure 5: Sunshade Sub-system - Exterior View

3.3 Skylight type

The third sub-system is the "Skylight" sub-system which comprises PV panels similar to that of the Sunshade type but is much larger. The panels are used to replace some of the vertically mounted glass-infill of the existing glass atrium at the southbound front entrance hall. About 100 m^2 of PV panels with a total peak power output slightly over 10 kW are installed (Figure 6).

Figure 6: Skylight Sub-system – Interior view

3.4 Generation Cost and Energy Payback of Photovoltaic Panel

"Levellised Cost of Electricity" (LCE) is a term commonly used to compare the cost of alternative power generation systems. LCE adopts a life-cycle costing approach and uses net present value calculations for the capital cost and operation and maintenance costs, as a means of comparing the average unit cost of electricity generated. The Stage 1 Study [1] revealed that LCE for PV power is between HK$2.2 to HK$4.1 per kWh, whilst the LCE for conventional fossil fuel power generation is between HK$0.2 to HK$0.4. The energy required for producing the PV panels can be recovered from the energy it generated within 4 years.

3.5 Power Conditioning Unit

Each power conditioning unit (PCU) consists of an inverter to convert the direct current (DC) output generated by solar cells into three-phase 380V alternating current (AC), which powers the electrical equipment in the building (Figure 7). High inversion efficiency has been maintained, as all the electricity generated will pass through the PCUs. Efficiencies of the installed PCUs are over 90%.

The output characteristic of PV cell varies at different solar irradiance levels. An automatic function called “Maximum Power Point Tracker” is incorporated within the PCU to track the optimum PV operating point when the irradiation changes.

Another function of PCU is to control the quality of the AC output. Harmonic content, power factor and frequency of its output are under constant regulation so that the power quality of existing distribution network will not be impaired.

Losses in the DC circuit are mainly attributed to copper loss in cabling. In order to minimise cable losses, a nominal voltage of 300 V DC is selected in order to cut down the current magnitude and in turn the cable losses. In addition, larger size cables are used and all cable lengths are maintained as short as possible for connecting to their associated PCUs. A detail schematic is shown in Figure 9.

Figure 7: Power Conditioning Unit

3.6 Grid Connection

As the electrical power generated from the BIPV system is used to supplement the mains supply and to reduce the electrical demand of the building, it is necessary to synchronize the PCU output to the mains supply and this is done automatically by the PCU. The grid voltages are fed to the PCU which will adjust its output voltage level, frequency and phase angle to match with the mains supply. When all these criteria are met and remain stable for a pre-determined period of time, the two sources will be connected in parallel to supply to the electrical loads of the building.

3.7 Safety

Safety is an important issue for any grid-connected renewable energy supply system. Other than complying with all local safety requirements, each PCU has a function called “Islanding” that can disconnect the BIPV system from the distribution network immediately whenever there is a failure in the mains supply. This is to avoid solar power being back-fed into the supply network and create potential danger to the personnel carrying out emergency repair on the supply network after the mains failure.

3.8 Operation and Maintenance

There is virtually no wear and tear on the hardware of the BIPV system itself as there are no moving parts. Maintenance is simple and easy as a result of the modular design of all electrical and electronic parts. In addition, the supplier guarantees PV cells that its conversion efficiency will not drop by more than 10% in 10 years’ time. The nominal life expectance of the PV panels is around 20 years. Natural cleaning by rain will be sufficient for PV panels as dust will not cause substantial drop in the conversion efficiency.

3.9 Monitoring System

There will be a one-year monitoring and evaluation period to assess the performance and reliability of this BIPV pilot project. A computerized monitoring system has been installed in order to closely monitor the performance of the BIPV system. Key monitoring parameters include solar radiation, wind speed, PV panel temperature, power output, cumulative energy output, power quality etc.

In addition, an information display panel (Figure 8) has been installed at the building main entrance to disclose real time operational data to the general public. The data include the solar radiation, power output, cumulative energy generated and CO_2 avoided by the BIPV system. The information will help the general public to understand the concept of PV technology.

Figure 8: Information Display Panel for Public

3.10 Aesthetic Effect

Besides generating electricity, the PV panels installed on the facade of the building can reduce the amount of solar heat entering the building interior as well as to allow sufficient amount of sunlight penetration. The reduction in solar heat will lead to an added advantage of lowering the energy usage of air conditioning system. In addition, the solar cells are arranged in such a way that an aesthetic pattern will appear in the interior space when daylight falls on the PV panels

4. Expected Performance

The project involves some 500 m^2 of PV panels with total peak installed capacity of 55 kW. It is estimated every year, about 40,000 kWh of electricity will be produced from the solar energy and about 23 tonnes of greenhouse gas (CO_2) and 40 kg of NO_x and 60 kg of SO_2 pollutant emissions which will be generated from the power station can be avoided. The BIPV system installed at Wanchai Tower helps to reduce greenhouse gas emissions, and hence makes a contribution towards a better environment.

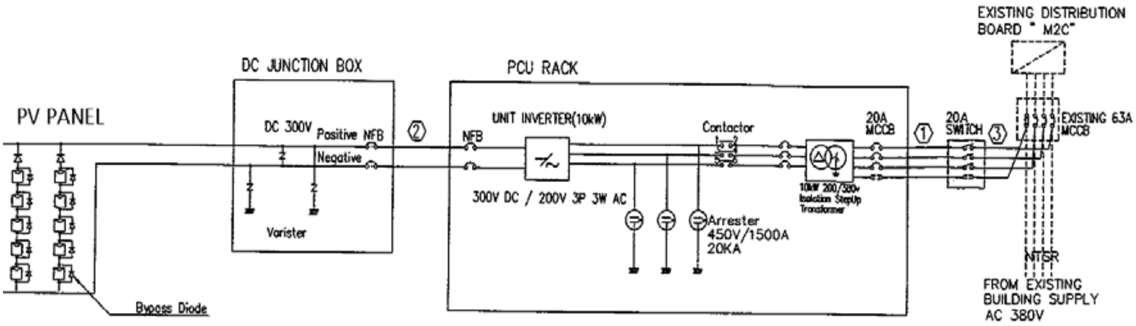
5. Conclusion

Hong Kong is a metropolitan city which consumes a lot of energy to sustain its economic activities. Provided that the manufacturing cost will continue to reduce, the application of BIPV system to generate electrical power is generally feasible in Hong Kong as it does not pollute the environment nor occupy much valuable space. The Wanchai Tower project provides operational data for assessing the performance of photovoltaic technologies in Hong Kong and also serves to demonstrate the potential use of solar power to the general public.

Reference

[1] The Executive Summary of the Stage 1 Study on the Potential Applications of Renewable Energy in Hong Kong, EMSD, December 2002. "http://www.emsd.gov.hk/emsd/e_download/wnew/stage.pdf"

[2] Paper on "Use of Renewable Energy Technology in an Urban City Environment", 2nd Symposium on Sustainable Development of Guangdong, Hong Kong and Macau – Strategic Partnership in the Pearl River Delta, April 2003, Hong Kong.



BIPV output connected in parallel with Mains concurrently and supplying distribution board

Mezz 2 – AC room
AHU No. 6

Figure 9: DC and AC Schematic of Skylight Sub-system