OVERVIEW OF BUILDING INTEGRATED PHOTOVOLTAIC INSTALLATION IN HONG KONG GOVERNMENT BUILDING

H.Y. YEUNG
Architectural Services Department, Government of Hong Kong Special Administrative Region
66 Queensway Road, Queensway, Hong Kong
e-mail : yeunghy@archsd.gov.hk

Abstract

Architectural Services Department is the works agent for facilities development of The Government of Hong Kong Special Administrative Region. We continue to promote sustainable development in Hong Kong construction industry by adopting of energy efficient devices and including of renewable energy technologies in our building design. This paper will briefly describe various types of building integrated photovoltaic system (BIPV). Our experience in applying building integrated photovoltaic system in two projects: a government office building and a primary school building will also be shared. Moreover, some of the design considerations and factors affecting the output of the photovoltaic panel will be discussed. Throughout different applications of building integrated photovoltaic system and its operation data, the feasibility of different types of BIPV systems in Hong Kong situation will be generally reviewed.

Keywords: Sustainable development, Renewable energy, Building integrated photovoltaic system

1. Introduction

According to the World Commission on Environment and Development, sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs. "Recently, with the rapid growth of global economics, energy consumption has also increased significantly. Demand for energy continues to grow but sources of the combustible fuels such as coal, oil and natural gas are limited. In addition, the increased burning of fossil fuels raises concerns over global warming and air pollution. The rapid depletion of fossil fuels and the emission of carbon dioxide from the conventional power generation plants have drawn worldwide attention to the conservation of energy and to look for alternative energy sources. In the ways to increase prosperity and improve the quality of life while reducing overall pollution and waste, the Council for Sustainable Development has set the sustainable development strategy for Hong Kong. Whereas, the promotion and development of renewable energy is one of its major policies. It has also set the target of having 1-2% of Hong Kong's total electricity supply met by renewable energy by 2012.

Solar energy is clean, unlimited and can be replenished naturally. Environmentally, solar energy has the significant advantages of producing no pollutant emissions in use, and by replacing the use of the fossil-fuel for generating electricity, solar electric system spares environment from tons of harmful emissions, such as carbon dioxide, nitrogen dioxide and sulphur oxides, which are the major contributors to smog, acid rain and global warming.

2. Photovoltaic Panel

The term "photovoltaic", commonly referred to as PV, is derived from a combination of "photo", the Greek word for light, and "Volta", the name of the Italian physicist, Alessandro Volta, who invented the chemical battery in 1800. The photovoltaic effect is the direct conversion of solar energy into electricity. PV power systems do not have any moving parts. They are reliable, require little maintenance and generate no noise or pollutants. PV systems are modular-building blocks (modules) and come in a wide range of power capabilities, from a fraction of a watt (e.g. solar watches and pocket calculators) to more than 300W.

PV cells are normally fabricated using special semiconductor materials that allow electrons, which are energized when the material is exposed to sunlight, to be freed from their atoms. Once freed, they can move through the material and carry an electric current. The current flows in one direction (like a battery), and thus the electricity generated is termed direct current (DC). The DC output from the PV modules can be converted to AC power by an inverter, and then may be connected into the building's service panel/main switchboard or local utility grid. The energy generated by PV modules can be used immediately or stored in batteries for later use. Normally, the excess energy generated in autonomous PV systems during sunny periods is stored in batteries. The batteries then provide electricity at night or when there is not enough solar radiation.

There are three basic types of PV cell technologies. Common PVs available are monocrystalline silicon/polycrystalline silicon, amorphous silicon and thin film technology of copper indium diselenide (CIS). The monocrystalline silicon cell is sliced from single-crystal ingot silicon and it has the highest conversion efficiency among all technologies as over 15%. The polycrystalline silicon cell is sliced from blocks of cast silicon and its has less efficient and expansive than monocrystalline silicon cell. It has the conversion efficiency of about 10-15%. The amorphous silicon has the lowest conversion efficiency among the other technologies as about 4-7%. The thin film technology of copper indium diselenide cell has the conversion efficiency about 9-12%.

3. Building Integrated Photovoltaics System

PV system being integrated into building envelope is called "building-integrated photovoltaics" (BIPV) and this accounts for a significant and rapidly growing number of applications. Building-integrated photovoltaics not only produces electricity from natural sunlight but also forms part of the building envelope, where the PV elements actually become an integral part of the building, often serving as the exterior skin. For example, the PV arrays take over the normal function of the roof (i.e. keeps out the weather) and is not just placed on top of the roof. PV specialists and innovative architects are now beginning to explore creative ways of incorporating solar electricity into their designs.

The economics of BIPV is improved by allowing some costs of the PV system to be shared by roof, building facade or overhang of the building. BIPV may be installed on roof or a vertical exterior wall panel facing the direction with most sun, i.e. replacing basic construction materials, such as roofing and glass walls with photovoltaics through BIPV. Thus the cost of the PV wall or roof can be offset against the cost of the building element it replaces.

There are three basic ways of integrating PVs in buildings: roof-based systems; facade systems / curtain walling system; and sunshades and sun-screens.

The roof-based systems are often free from over-shadowing. The roof slope can be selected for high performance. It may be easier to integrate PVs aesthetically and functionally into a roof than a wall.

Facades have significant development potential. PV cladding can be considered to be panes of glass to which PV cells are applied and so massive glazed facades can be built upon. The mullion/transome stick system is the most commonly adopted for curtain walling system. PV modules can be fabricated and incorporated easily as factory-assembled double-glazed units, the outer pane being laminated glass-PV-resin-glass and the inner pane, glass with a sealed air gap between.

The sunshade systems normally consist of panels set slightly off from the building to allow for drainage and ventilation. As such they are very suitable for PV integration. The ventilation gap (e.g. 100mm or more) has the beneficial effect of reducing temperatures, thus enhancing performance. It also provides space for cable routes. It can also provide shading for the direct sunlight, penetrating into the indoor and hence reduce the burden for air conditioning plant.

The use of PVs should be part of the total energy approach for the building and the application of BIPV should be carefully considered as the required PV area and the construction cost can vary enormously according to the desired goal.

PVs are worth considering if the following key factors are right: The solar radiation at the site is the most important factor and good access to the site. Besides, the project should have an electrical requirement that much of the output from the PVs installation can be used on site. And, the availability of adequate surface area for installation of PV is also a critical factor. The design team should carry out the initial assessment of PV feasibility by studying the following factors: location and direction of space available for installation of PV panels, building form and aesthetics of the building, PV cell type and its combination, tint angle of PV panels, its operating temperature and cost.

In brief, the more solar radiation and the more uniform the radiation is on the array, the better the PV output is. The topography of the site should be studied carefully. In urban areas self-shading by the building itself and overshadowing by other buildings is very common in the situation of Hong Kong. It is desirable to have a site with as little shading by hills and other geographical features as possible since this will reduce the electrical output. Overshadowing by nearby buildings and self-shading due to the architectural form should be avoided wherever feasible. Where shading is unavoidable, careful selection of components and configuration of the array can help minimize losses. Computer programmes are available to assist in analyzing the loss of PV output due to shading effect.

Orientation of PV array is important but there is some flexibility for improvement to deal with this constraint. It is desirable to locate the building on the site so that PV array is approximately with 22° tilted and facing south. This will permit collection of more solar irradiance to the solar panels.

The potentially high temperatures associated with building elements specifically designed to capture the solar radiation should be carefully considered. The more solar radiation it receives, the higher temperature the solar panel is. In order to keep the operating temperatures as low as possible to maintain good performance of PV module, it is desirable to ventilate the back of the PV modules to improve the efficiency of the solar arrays. In general, as long as the heat from PV modules does not build up and is removed by ventilation there should not be a major problem. Hence, the local wind regime should be considered as part of the PV application for ventilating the solar arrays.

4. EMSD HQs

The EMSD Headquarters is located at the ex-airport near Kowloon Bay. Although it is located in the urban area, the district is not densely built and without ultra high rise building nearby. This is suitable for the adoption of photovoltaic technology.

Fig. 1 PV panels & its surrounding environment

The EMSD Headquarters is, currently, equipped with the Hong Kong's largest photovoltaic panel system comprising over 2,300 photovoltaic panels including BIPV (Fig. 1). The peak electricity generation rate can be up to 350kW. Monocrystalline PV cells are used in the photovoltaic system so as to achieve the highest conversion efficiency. It is almost the same as the electricity consumption of a large chiller plant.

Fig. 2 BIPV in Viewing Gallery

All the panels are faced south and inclined at 22° to the ground to receive most of the available solar radiation. The tinted panels can also provide the self-cleaning effect when it rains. The BIPV panels are integrated at the roof glass structure of the Viewing Gallery (Fig. 2). With carefully planned location of the PV cells, the daylight at the Viewing Gallery is not compromised while solar energy can be captured. Besides, the spacing between rows of PV panels is enlarged with due consideration of the shadowing effect and daylighting effect. This could generate electricity from the solar irradiation and also reduce the electric lighting power by the shaded sunlight. The PV system is grid-connected to the electrical distribution system of the local electricity company. This could enhance the reliability of the system. While considering the basic electricity demand of the building, the power generated by the PV system could be completely utilized within the building without any influx to the supply network.

The estimated electricity generation is around 300,000 kWh to 400,000 kWh annually which represents 3 to 4 percent of the building's electricity consumption or equals to the total annual electricity consumption of 90 families in Hong Kong. Besides this, using the PV panels to generate electricity also reduces the power stations' carbon dioxide emissions by about 280 tonnes every year.

Fig. 3 PV panels & BIPV

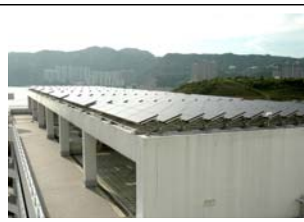
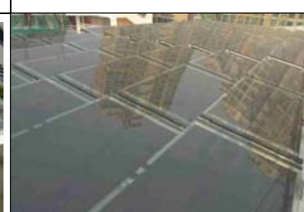
5. Ma Wan Primary School

As this project is the first purpose built school with solar-energy design, it serves as a model and research tool for the future school design of sustainable development. Architectural Services Department and Education Bureau (formally Education and Manpower Bureau) advocate to demonstrate how smart energy strategy can be implemented for contemporary academic approach while lowering its operating cost simultaneously.

The school is located in an outlying island, Ma Wan. The school is orientated to the southwest for daylighting and free of overshadowing from the adjacent residential towers. Moreover, there is plenty of natural wind for ventilation and lower the operating temperature of the solar panel. This is eminently suitable for PVs.

There are three different PV technologies applied in this school project and their details are listed in Table 1 and the photographs.

Table 1 Detail of BIPV in Ma Wan Primary School

Type of BIPV	Thin-film copper indium diselenide sunshades	Polycrystalline silicon skylight	Amorphous silicon sunshades
Peak	28.8	4	7.2
PV Panel Area (m2)	432	50	216
PV cells type	Thin film copper indium diselenide	Polycrystalline silicon	Amorphous silicon
Characteristics	Installed in roof top as electricity generating device ; provide extra insulation and protection from solar heat gain to indoor	Incorporate as part of the glass modules to suit the curved design of the roof-skylight over the lobby stair; electricity generating device; shading of sunlight and weather protection	Installed in roof top as electricity generating device; provide extra insulation and protection from solar heat gain to indoor
Energy output (kWh)	26000	3300	7200
Final yield (kWh/kW$_p$/year)	940	829	1009
Performance Ratio	0.65	1.11	0.93
Photos			

$$\text{Final Yield} = \text{Total energy output (kWh)/ Rated power of the PV arrays } (kW_p) \qquad \text{Eq 1}$$

$$\text{Performance Ratio} = \text{Final Yield (hours)/ Reference Yield (hours)} \qquad \text{Eq 2}$$

The Final Yield (kWh/kW_p) is the total net energy output of the PV array normalised to the rated power of the PV array. It is used to compare the different PV power systems regardless the size of the systems. The performance ratio is the ratio of the final yield to the reference yield. It is also widely used to indicate the overall effect of losses on the PV array's rated output due to array temperature, incomplete utilisation of the irradiation, system components/ wirings inefficiencies or system failure. By comparing with overseas and local experience, similar operating data is obtained for the overall performance.

6. Conclusions

To promote energy efficiency, adoption of renewable energy technologies like solar PV technology wind turbine technology as integral parts of the energy progamme become a global trend for sustainable development. By comparing with the experience of the other country and the local PV system, similar operating data is obtained for the overall performance.

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