Overview of Building Integrated Photovoltaic (BIPV) Systems in Hong Kong

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Abstract - Alternative energies, other than fossil fuels, are the one of the logical ways for reducing green house gas emissions and for sustainable development. Hence, in recent years, governments all over the world have been stepped up their push in exploring more opportunities in this area. Photovoltaic (PV) technology is, of course, one of promising candidates in alternative energies in most parts of the world. It is predicted that the cumulative worldwide installed PV capacity will reach 70GW by 2020 [1].

To cope with the problem of high initial cost of PV installations, the concept of building-integrated photovoltaics (BIPV) has been introduced; such that the PV panels can be used for serving purposes of some standard building components other than generating electricity. By this way the marginal cost of a PV system can be greatly reduce to a more acceptable level.

In Hong Kong, a number of medium-scale BIPV systems were completed in last few years. These BIPV projects included government building, commercial building, schools, institutional building. The power rating the BIPV system for each project is in the order of tens of kilowatts. Most of these BIPV systems are gird-connected type to eliminate the bulky and troublesome battery banks. Some of these projects are retrofitting on existing buildings; while some are parts of a new building. The paper will give some details on the design of these PV systems.

INTRODUCTION

Usually, general public have the impression that application of solar energy is not relevant to urban areas with high population density. However, "sustainable development" has become the worldwide trend of city development. In the recently released "The First Sustainable Development Strategy" of the Hong Kong Special Administration Region (HKSAR) Government, renewable energy or alternative energy, is one of the three key areas [2]. Solar energy is regarded as one of the possible potential source of renewable energy in Hong Kong, along with wind energy and waste-to-energy. In urban environment, building integrated photovoltaics (BIPV) system is an attractive application of solar energy. In fact the annual rate of PV utilization grew worldwide from 20% in 1994 to 40% in 2000 (Figure 1)[1]. At the end of 2002, close to 1330 MW was installed through out the world. It is predicted that the cumulative installed PV capacity will reach 70 GW by 2020 [1].

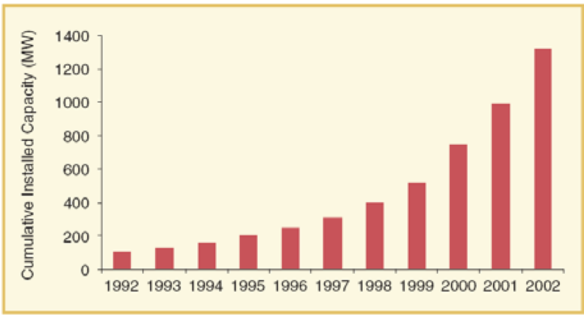

Figure 1: Worldwide installed PV power (source: [1])

With a careful design in suitably selected applications, building integrated photovoltaics (BIPV) is a good application of solar energy in urban areas. This is especially true for office buildings in tropical and sub-tropical cities. For BIPV systems in Hong Kong situation, it is believed that AC grid-connected is the best choice because of several unique geographical, economical and social characteristics of Hong Kong. A brief schematic diagram on the concept of these grid-connected BIPV systems is illustrated in Figure 1.

In designing an AC grid-connected BIPV system for Hong Kong, engineers have to consider a lot of variable factors such as local climate situation, property location, shadow profile, orientation of PV panels, panel configuration (type of wiring and/or using more than one type of panels), inverter configuration, etc. It is better to make a choice based on a detailed calculation to find the optimized system configuration for a BIPV system.

BENEFITS OF BIPV SYSTEMS

Conventionally, the major obstacles in application of photovoltaic technology are [3]:

- The high capital cost of the PV panels
- The requirements of a large and bulk supporting structure and its associated cost,
- The requirements of a large and bulk battery set to carry the system during night time and bad weather conditions, and

- The high capital, replacement and maintenance cost of the battery set, which needs regular maintenance and be replaced every 3 to 5 years.

However, all these problems are not that critical in the BIPV case. First of all, the high capital cost of PV panels is large offset by the cost of the otherwise required curtain glass panels or metallic cladding panels, which are also expensive. And this is referred as the "avoided" cost. Secondly, the mounting and supporting requirements of the PV panels in BIPV systems are largely the same as ordinary glass panes. Hence the original supporting structures for the panes can be used, with the exception that some minor modifications for allowing the routing of wires. The two problems related with the battery set can be totally eliminated, if a grid-connection to the BIPV system is established.

In addition to the avoidance of the conventional obstacles in application of PV technology, grid-connected BIPV system 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 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 BIV system [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.

SOME OF THE BIPV PROJECTS IN HONG KONG

In Hong Kong, a number of medium-scale BIPV systems were completed in last few years. These BIPV projects included government building, commercial building, schools, institutional building. The power rating the BIPV system for each project is in the order of tens of kilowatts. Most of these BIPV systems are gird-connected type to eliminate the bulky and troublesome battery banks. Some of these projects are retrofitting on existing buildings; while some are parts of new buildings.

Details of these projects will be given in the case studies of the following section

CASE STUDIES

BIPV systems on CYC building of HKU

This is a retrofitting project [4], in which PV panels of total area 25 m × 4 m (H × W) were installed on a south-west facing vertical façade of the CYC building in the University of Hong Kong. The location of the building is by the side of hills in the Western district of Hong Kong Island, the building is an office building and the BIPV system is a grid-connected BIPV system. The system is also act as a thermal buffer to reduce the heat gain of the building from the strong sunrays during the sun setting period. The system was made from two types of thin-film PV panels; each type of panels occupied 25 m × 2 m (H × W) vertical area. Thin film panel has the advantages of low cost and the external appearance is similar to those normal curtain wall glass panes. In fact, the mounting of these panels in the project was exactly the same as those for normal curtain wall glass panes, and modular structure concept is used in the assembly process.

Figure 2: Photo of the BIPV system on CYC building of HKU

Totally two inverters are used in the system, each for each type of the thin film panels; hence basically it is two electrically independent BIPV systems. The total peak power generated is about 4.3 kWpeak, and the average annual yield of the system is about 3,200 kWh. A comprehensive monitoring system was installed there to measure the local weather conditions, global & in-plane solar irradiance, and DC & AC current, voltage and power. The system was completed in 2001 and it has been satisfactorily operated in the last few years. A photo of the system is shown in Figure 2.

BIPV systems of Hong Kong Science Park

Hong Kong Science Park (HKSP) is an essential state-of-the-art infrastructure that promotes the development of innovation and technology in Hong Kong. It is designed to accommodate companies of all sizes and stages of development and to promote interaction and innovation at both a local and global level. It is located on a 22-hectare site on the Tolo Harbour waterfront, in Pak Shek Kok of Shatin in Hong Kong.

HKSP phase 1 is to be comprised 10 buildings as shown on Figure 3. Buildings 1, 2 and 3 are well on schedule and officially opened for operation in June 2002. The remaining buildings will be completed by the early 2004.

The PV systems for HKSP phase 1 with a total capacity about 198kW to grid connection were planned to be installed in eight buildings. Details of BIPV installed capacity are shown in Table 1.

Figure 3: Block plan for HKSP Phase 1 to show the location of Buildings

Phase	Building	Type of Building	BIPV System Capacity (kW)
1a	2	Core Building	18
1b	4a	Photonic Centre	45
1b	4b	Wireless Centre	25
1b	5	Innovation Centre	50
1c	6	Biotechnology Centre	15
1c	7	Corporate Building	15
1c	8	Corporate Building	15
1c	9	Core Building	15
		Total:	198

Table 1: Details of the BIPV installed system for Hong Kong Science Park Phase 1.

The design and installation for the BIPV laminates are based on building integrated approach. The laminates shall be parts of the building construction materials and fit for the overall architectural requirements in outlook, protection, and thermal insulation and harmonise with building construction.

The BIPV systems in HKSP can be divided into two types: roof rack BIPV systems and sun shading BIPV systems. For the sun shading BIPV systems, they were designated as the sites for the photovoltaic "skin". BIPV was incorporated into the design after the building's general appearance had already been decided upon, so the installation was made to harmonize with the established design concept. For the roof-top BIPV systems, BIPV modules have been designed as sun shelter proofs to the buildings. They can be harmonized with existing building architecture design.

All BIPV systems were designed together with all other parts of the building and the monitoring of the BIPV systems for the buildings are also part of the energy management system of the respective buildings.

Details of these systems for individual buildings in Phase 1a, 1b and 1c are shown in Table 2, while the photos of the roof rack BIPV systems for buildings 2, 4a, 4b and 5 are shown in Figures 4 to 6.

Phase 1a - Sun Shading BIPV Systems for Building 2

Location	Middle section of the building
Orientation	60 deg to horizontal facing south-west
Type of panels	Monocrystalline
No. of panels per string	6
No. of strings	20
Total no. of panels	120
Total PV panel area	129.8 m^2
System rated power	18.48 kW
No. of inverters	One complete set of grid connected inverter

Phase 1b - Roof and facade of BIPV Systems for Buildings 4a, 4b & 5

Building	4a	4b	5
Application	Façade and roof sun proof shelter and area		
Location	Façade and roofing		
Orientation	Facing SE & NW	Facing SE & NW	Facing SW and NE
Type of panels	Monocrystalline Silicon solar Cell		
Rated power	45kW	25kW	50kW
Total no. of panels	148+148 for SE & NW roof	92+92 for SE & NW roof	36+36 for SE & NW roof
	80+80 for SE & NW façade	120 for SE façade	252 for SW façade
Total panel area	868 m^2	544 m^2	876 m^2

No. of inverters	1 set of grid connected inverter for each building
Type and size of customer's load	>100kW electric load of chiller plant for each building.

Phase 1c-: Roof rack BIPV systems for Buildings 6 to 9

Building	6	7	8	9
Application	Roof sun proof shelter area			
Location	Roofing			
Orientation	Fitting with Roof layout			
Type of panels	Monocrystalline Silicon solar Cell			
Total no. of panels	208	160	160	180
Total PV panel area (sq.m)	177	136	136	153
Inverter Number & Size	One complete set of grid connected inverter, 15 kW output for each building			
Type and size of customer's load	>100kW electric load of chiller plant for each building.			

Table 2: Details of the systems for individual buildings for HKSP Phase 1.

Figure 4: Photo of the BIPV system on Building 2

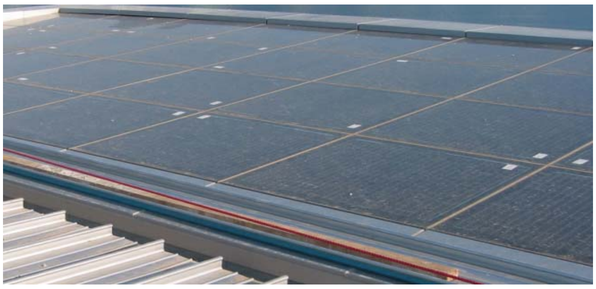

Figure 5: Photo of the Roof rack BIPV system on Roof of Building 4a

Figure 6: Photo of the facade and roof of BIPV system on Building 5

<u>BIPV systems of Wan Chai Tower</u>

It is a retrofitting project; three BIPV systems were added onto a government office building known as Wan Chai Tower in the Wan Chai area on Hong Kong Island. The three systems are Roof Rack BIPV system, Sun Shading BIPV system and Skylight BIPV system. A comprehensive monitoring system was installed there to measure the local weather conditions, global & in-plane solar irradiance, UV irradiance, and DC & AC current, voltage and power, current and voltage harmonic contents. The system was completed early this year and then immediately a one-year of close monitoring period was started. From the collected data, the performance of BIPV systems at different part of a building in Hong Kong situation will be analyzed. Details of these three systems are shown in Table 3, while photos of the Roof Rack BIPV system are shown in Figure 7 to 9.

System 1: Roof Rack BIPV System

Location	Roof
Orientation	10 degree to horizontal, facing south
Type of panels	Polycrystalline
No. of panels per string	18
No. of strings	7 string per group, 2 groups
Total no. of panels	252
Total PV panel area	164.70 m^2
System rated power	20.16 kW
No. of inverters	1 inverter per group

System 2: Sun Shading BIPV System

Location	Middle section of the building
Orientation	Vertically facing south
Type of panels	Monocrystalline
No. of panels per string	21

No. of strings	8 string per group, 2 groups
Total no. of panels	336
Total PV panel area	231.84 m^2
System rated power	20.16 kW
No. of inverters	1 inverter per group

System 3: Skylight BIPV System

Location	Ground floor lobby
Orientation	Vertically facing south
Type of panels	Monocrystalline
No. of panels per string	5
No. of strings	7 string
Total no. of panels	35
Total PV panel area	95.98 m^2
System rated power	10.08 kW
No. of inverters	1 inverter per group

Table 3: Details of the systems for Wan Chai Tower

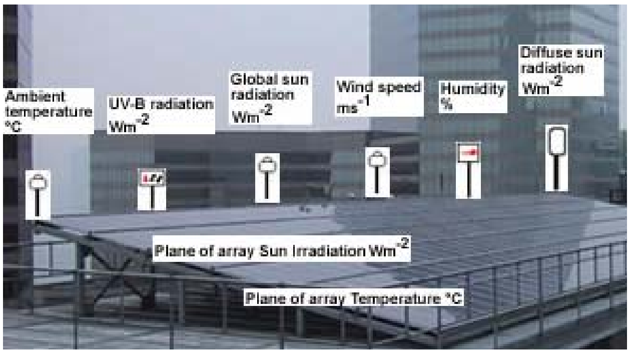

Figure 7: Photo of the Roof Rack BIPV system on roof of the Wan Chai Tower in Hong Kong (locations of some of the monitoring sensors are indicated)

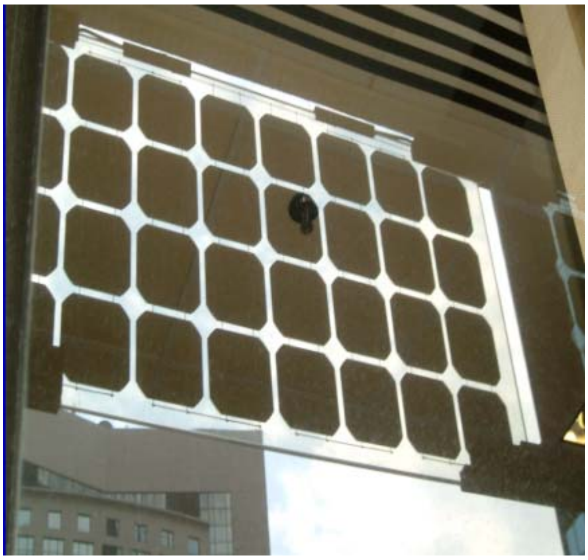

Figure 8:The interior view of the Sun Shade BIPV system of the Wan Chai Tower in Hong Kong

Figure 9:The interior view of the Skylight BIPV system of the Wan Chai Tower in Hong Kong

<u>BIPV system on a building at Peking Road</u>

It is a commercial project, a BIPV system was installed into a 29-storey commercial building including shopping arcade, restaurant and office located at Peking Road in Tsim Sha Tsui. The PV panels of total area 200 m^2 were installed on a south-east facing vertical top of this building. The BIPV system is standalone system with batteries to drive motors for the blind.

The BIPV system was made from 144 numbers of double laminated 8+8mm heat-strengthen glass PV module; each of module occupied 72 numbers of 100x100mm silver colour polycrystalline silicon cell.

One inverter is used in the system. The total peak power generated is about 7.2 kWpeak. The system was completed in Dec 2002. A photo of the system is shown in Figure 10.

Figure 10: Photo of the BIPV system at the top part of on a building at Peking Road, Hong Kong

BIPV Systems of Ma Wan School

In 2003, fours BIPV systems are being installed on to a new primary school in the Ma Wan Island of Hong Kong. It is a completely integrated system, all the BIPV subsystems were designed together with all other parts of the building, and the monitoring of the BIPV subsystems is also part of the energy management system of the building. Two of the BIPV systems are used deck shadings, one is used as roof-light and the fourth one is used on canopy. These systems will also be used for educational purposes for teaching students on the passive and active uses of solar energy. Details of these four systems are shown in Table 3, while a computer simulated image of the completed school is shown in Figure 11. The whole project will be completed by the end of this year.

System 1

Application	Deck shading
Type of panels	CIS (Copper Indium Diselenide) thin film
No. of panels per string	5
String VDC	83
No. of strings	24
Total no. of panels	120
System rated power	2.4kW
No. of sub-system	6

System 2

Application	Deck shading
Type of panels	CIS (Copper Indium Diselenide)
No. of panels per string	15
String VDC	249
No. of strings	24
Total no. of panels	360
System rated power	14.4kW
No. of sub-system	1

System 3

Application	Roof Light
Type of panels	Polycrystalline
No. of panels per system	24-28
System VDC	294-319
No. of inverters	2
Total no. of panels	52
System rated power	2.0kW
No. of sub-system	2
Total Annual yield	4,855kWh

System 4

Application	Canopy
Type of panels	Amorphous Silicon
No. of panels per string	3
String VDC	136
No. of strings	7
Total no. of panels	21
System rated power	2.4kW
No. of sub-system	3

Table 3: Details of the systems for the Ma Wan School

Figure 11: Computer simulated image of the completed Ma Wan Primary School with BIIPV systems on it

Others

Apart from the above-mentioned projects, some BIPV systems in different types of building under construction are summarized in Table 4.

Project	Project type	PV size	Completion date
EMSD new Headquarters	Grid-connected BIPV system	300kWp of monocrystalline PV models	April 2005
NTS Police headquarters at Tsuen Wan	Standalone BIPV system	15.84kWp polycrystalline PV modules	Mar 2005

Police and Fire stations at Chok Ko Wan	Integrated PV Roofing grid connected system	80kWp polycrystalline PV modules	Jul 2004
Police Dog School at Sha Leng	Standalone BIPV Skylight system	5kWp monocrystalline PV modules	Oct 2003
Fire Station at Sha Tau Kok	Standalone BIPV Skylight system	5kWp monocrystalline PV modules	Oct 2003
Grandeur Terrace (PSPS) Residential Building at Tin Shui Wai	Integrated PV Roofing grid connected system	14kWp single-crystalline PV modules	May 2003
Kadoories Farm Reception Building	Integrated PV Roofing	4kWp 60 m^2 EFG crystalline PV modules	Feb 2002

Table 4: Summary of other recently completed BIPV system installations for Hong Kong

THE WAY FORWARD

In early 2003, the Electrical Mechanical Services Department (EMSD) of Hong Kong Special Administrative Region (HKSAR) Government released a consultancy report — The Stage 1 Report of the "Study on the Potential Applications of Renewable Energy in Hong Kong" [5]. The study in the report identified that photovoltaic, wind energy, energy from waste and building integrated fuel cell are four potential sources of renewable energy for wide scale applications in Hong Kong. Furthermore, the study also suggested that the initial targets of local renewable energy contribution to annual power demand should be set at: 1% by 2012; 2% by 2017; and 3% by 2022.

In May 2005, the HKSAR Government announced "A First Development Strategy for Hong Kong" [2]. The Strategy officially put in one of the targets as "To aim to have between 1 and 2% of Hong Kong total electricity supply met by power generated by renewable sources by the year 2012, with this target being subject to regular review in the light of advanced in technological solutions and emerging sustainability considerations."

Also in May 2005, the Electrical & Mechanical Services Department of the HKSAR Government released the "Technical Guidelines on Grid Connection of Small-scale Renewable Energy Power Systems" [6]. The aim of the guidelines is for smoothing out the application procedures for grid connections from these renewable energy systems.

At the same time, the Buildings Department of the HKSAR Government may consider to give incentives to building developers to incorporate "green features" in to buildings, BIPV system may be considered as one of these "green features".

With all the above development, therefore integrating BIPV system into green features of building should be the way forward for Hong Kong in the aspect of applications of solar energy. This approach will enable PV panels to serve multiple purposes, and also reduce the *marginal* cost of the BIPV system per kW of installed capacity, or per kWh of expected annual yield. The authors are expecting that after a few demonstration projects from the Government and the public sector, private building developers will join into this wave of applications of BIPV systems.

Surely, grid-connected BIPV systems should be the main stream of BIPV systems in Hong Kong situation, instead of stead alone system. This will take away the high initial cost, bulky space requirements and troublesome maintenance issues associated with the battery storage system. However, this needs some change of the local regulations of electricity supply.

CONCLUSIONS

In this paper, the concepts and benefits of BIPV system were presented. Several major cases of completed or ongoing BIPV systems in Hong Kong were detailed. The development directions in the near further for Hong Kong were also discussed. Renewable energy is surely becoming a more significant part in our daily life in order to achieve a sustainable development, and we will see more and more BIPV systems will be incorporated into existing and new buildings.

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