Performance Evaluation of a Large Building Integrated Photovoltaic System in Hong Kong

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Abstract

Most of our electricity is generated through burning of fossil fuels. However, combustion of fossil fuels releases greenhouse gases which have already been identified as a potential major contributor to global warming and climate change. Utilizing renewable energy sources such as solar to generate clean electricity is one of the means to reduce the environmental impacts resulting from the use of fossil fuels. The use of renewable energy power systems such as photovoltaic system to generate electricity is rapidly expanding throughout the world.

In May 2005, the photovoltaic system installed on the roof of the headquarters building of the Electrical and Mechanical Services Department (EMSD) of the Government of HKSAR came into operation. With an installed capacity of 350 kW, the building integrated photovoltaic (BIPV) system is one of the largest of its kind in the Far East. The installation consists of more than 2,300 photovoltaic modules and has a total surface area of about 3,100m^2.

It is not common to have such a large photovoltaic system installed in a single building, the performance of the system was therefore closely monitored for a full year cycle. The technical data collected are used to assess the effectiveness of large-scale photovoltaic system in generating electricity under the geographical and climatic conditions of Hong Kong. The presentation discusses the design concept and reviews the performance of the grid connected photovoltaic system installed in EMSD headquarters building.

Keywords: *grid connection, photovoltaic system in Hong Kong, performance*

1. INTRODUCTION

The burning of fossil fuels such as coal, oil and natural gas, for generating electricity will release air pollutants and other greenhouse gases. The emission of greenhouse gases has now been accepted by the vast majority of the world's scientists as the main attribution to the global warming and climate change. The consequence of global warming such as rise in sea level and gradual rise of the Earth's surface temperature, has far-reaching impacts on our environment as well as our ecosystems. On the other hand, the air pollutants generated from the burning of fossil fuels in the power plants, such as sulphur dioxide (SO_2), nitrogen oxide (NO_x) and respiratory suspended particulates (RSPs) etc. are also the major contributors to the air pollution.

In recent years, Hong Kong faces serious air quality problem, the Air Pollution Index (API) of a number of places in Hong Kong stay at high level from time to time resulting in the smog phenomenon. There is a pressing concern on the air pollution. The Government has initiated a number of actions to address this problem.

Over the past few years, there have been an increasing number of government projects incorporated with renewable energy power systems such as photovoltaic systems to generate clean electricity. The projects include Wanchai Tower, Science Park, Castle Peak Hospital as well as a large-scale photovoltaic system in the new Headquarters of the Electrical and Mechanical Services Department (EMSD).

The new EMSD Headquarters is a seven-storey building located in Kowloon Bay. This building has utilized various kinds of renewable energy resources including solar and wind. Apart from the installation of two micro-wind turbines, a large-scale photovoltaic system has also been installed on the roof of the building. The installed capacity of the photovoltaic system is 350 kW involving a total area of around 3,100m^2 of PV panels. It is the largest photovoltaic installations within the territory. It is also one of the largest in the Far East.

It is uncommon to have such a large photovoltaic system installed in a single building. With a view to understand the effectiveness of large-scale photovoltaic system in generating electricity under the geographical and climatic conditions of Hong Kong, a 12-month system performance monitoring of the system was carried out by the EMSD in 2006.

2. PHOTOVOLTAIC SYSTEM CONFIGURATION

The photovoltaic system is made up of 2,357 standard photovoltaic modules mounted on the roof of the building. Each of the standard photovoltaic module is rated at 150 W. It is constructed in the form of a rectangular panel, which consists of 72 series-connected 125 mm x 125 mm mono-crystalline silicon photovoltaic cells. All the standard photovoltaic modules are mounted on the supporting rack on the roof of the building. The panels are facing southwards with a tilting angle of 22^{o} to receive maximum solar irradiation in the course of a year.

Fig. 1: BIPV installation in EMSD Headquarters

In addition to the standard photovoltaic modules, there are 20 sets of photovoltaic glass laminates installed above the viewing gallery of the building. Each photovoltaic glass laminate consists of 135 series-connected 125 mm x 125 mm mono-crystalline silicon photovoltaic cells sandwiched between two sheets of glass laminates.

Fig. 2: Photovoltaic glass laminates installed at the Viewing Gallery

The direct current (D.C.) electricity generated from the photovoltaic system is converted into three phase 380V alternating current (A.C.) by four power conditioning units, working in parallel for this system. The output capacity of the inverter integral with each power conditioning unit is 100 kVA. Another function of the power conditioning unit is to control the quality of the AC output. In this connection, an isolating transformer has been integrated into each of the power conditioning unit for the purpose of power regulation. Power factor and frequency of its output are under constant regulation to ensure the power quality of the existing distribution network will not be impaired.

Losses in the D.C. circuit are mainly attributed to copper loss in cabling. In order to minimize cable losses, a nominal voltage of 480V D.C. is selected in order to cut down the current magnitude and in turn the cable losses.

The photovoltaic system is connected to the utility grid to operate in parallel with the grid. The electricity generated from the system will be consumed by the building electrical load.

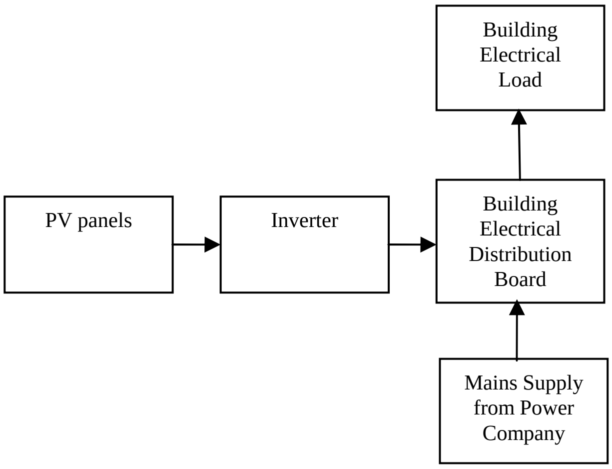

Fig.3: Block diagram to illustrate the photovoltaic system and the grid connection arrangement

3. DATA COLLECTION

Key monitoring parameters such as voltage, current, frequency input and output power were recorded and collected at 15-minutes interval by the controller integral with the inverters.

Climatic data such as the global solar radiation (GSI), mean air temperature, relative humidity, etc. were obtained from the weather station of Hong Kong Observatory (HKO) located in King’s Park over the monitoring period.

4. DATA ANALYSIS

4.1 Electricity output

The annual output in the year of 2006 was 330,000 kWh with a monthly average of 27,500 kWh which can be translated into a saving of about $320,000 per annum (or $26,600 per month).

4.2 Environmental Benefits

Assuming that the average carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxide (NO_x) emission is 0.81 kg / kWh, 0.0026 kg / kWh and 0.0013 kg / kWh respectively, the BIPV installation helps to avoid emission of about 267,000 kg of CO_2, 860 kg of SO_2 and 430 kg of NO_x into the atmosphere resulting from the burning of fossil fuels for electricity generation.

4.3 Final Yield

The final yield (Yf) is defined as the total energy output (kWh) of the photovoltaic array normalized to the rated power of the photovoltaic array (kW_p). This normalized indicator is given to compare energy output of different photovoltaic power systems regardless the size of the particular system.

The annual final yield of the photovoltaic system is 943 kWh / kW_p.

From the performance analysis of 150 grid-connected photovoltaic systems complied by the International Energy Agency [1], the typical average annual values for photovoltaic systems installed in the following countries are:

a) Switzerland – 790 kWh / kW_p;

b) Italy – 864 kWh / kW_p; and

c) Japan – 990 kWh / kW_p.

The annual final yield of 943 kWh / kW_p for the photovoltaic system in EMSD Headquarters is comparable to these overseas installations.

4.4 Performance Ratio

In addition to the total net energy output of the photovoltaic system, a normalized indicator of performance is also generally used to compare photovoltaic systems of different sizes and local weather conditions, which is the Performance Ratio (PR).

Performance Ratio (PR) indicates the overall effect of losses on the photovoltaic array's rated output to array temperature, incomplete utilization of irradiation (such as loss of irradiation due to dirt), and systems components / wirings inefficiencies or system failure etc.

PR is defined as [Final Yield / Reference Yield]. Final Yield is as defined in section 4.3, and Reference Yield is the ratio of "the total in-plane irradiation" (kWh / m^2) to "the module's reference in-plane irradiance" (1 kW / m^2), which representing solar energy theoretically available per kW peak of installed photovoltaic modules.

The PR of the system in EMSD Headquarters is 0.8. The PR is comparable to the results obtained form overseas studies (ranging from 0.3 to 0.91) [1].

4.5 Global solar radiation in 2006

The global solar radiation at King's Park recorded by the HKO for 2006 and for the 30 years long-term average (period between 1971 and 2000) is shown in Figure 4. The annual global solar radiation in 2006 was 1,240 kWh / m^2, which is 8 % lower than that of the long-term average value of 1,340 kWh / m^2.

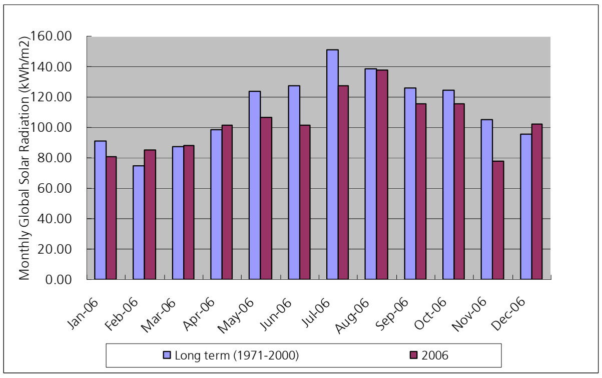

Fig. 4: Monthly global solar radiation recorded by the Hong Kong Observatory

5. MAINTENANCE

Since the photovoltaic modules have no moving parts, the maintenance requirement is minimal. Routine inspection or repair works upon failure of components will be carried out on needed basis.

6. CONCLUSION

In conclusion, the performance of EMSD photovoltaic system has performed well and is comparable with a number of local and overseas photovoltaic installations. The photovoltaic system has exhibited good reliability without any grid connection problems since commissioning. This project has demonstrated a successful photovoltaic power system operating under the typical conditions of Hong Kong.

7. REFERENCES

[1] "Operational Performance of", International Energy Agency (IEA): IEA-PVPS Report T2-03: 2002