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An analysis of a medium size grid-connected building integrated photovoltaic (BIPV) system using measured data

D.H.W. Li*, S.K.H. Chow, E.W.M. Lee

Building Energy Research Group, Department of Civil and Architectural Engineering, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong SAR, China

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ABSTRACT

There are many immediate adverse effects on the environment such as large amount of greenhouse gases and pollutants emissions from the burning of fossil fuels for electricity generation. Photovoltaic (PV) systems are promising solar energy applications to generate electricity without emitting pollutants and requiring no fuel. In modern urban cities, most buildings are high-rise with limited spaces for PV system installation, the concept of building integrated photovoltaic (BIPV) would be an appropriate alternative form of the application. This paper studies a medium size grid-connected BIPV system mounted in an institutional building. Technical data including solar radiation and energy output were analyzed. The operational performance and electricity benefits of the BIPV system were examined in terms of cost, energy and environmental aspects. The monetary, embodied energy and greenhouse gas payback periods were estimated and reported. To shorten the payback periods, the BIPV system should incorporate with more passive energy-efficient architecture designs. This on-site measurement contributes the most accurate method of obtaining reliable data for determining the performance of various designs under the actual operating environments for evaluation.

1. Introduction

Fossil fuels as the main energy resource for many countries deplete gradually. The burning of fossil fuels is the largest source of emission of carbon dioxide (CO_2) which is one of the greenhouse gases (GHG) causing global warming and climate change. Carbon sequestration is costly and fossil fuel is not a permanent solution for generating energy. The global environmental hazard posed by emissions from burning fossil fuel has become a strong driving force for the use of renewable and sustainable energy. Some energy performance paradigms such as zero (net) energy building for emissions free of NO_x, SO_x, CO_2 and particulates are widely studied [1]. There are many forms of renewable energy (RE) including solar electric, solar thermal, geothermal heat, hydro-electric, wind turbine and tidal and wave power. The large-scale integration of renewable energy should be seen as a way of approaching renewable energy systems [2,3]. However, large-scale integration of electricity production from fluctuating renewable energy sources into the electricity system must address the challenge of designing integrated regulation strategies of a complex system of distributed power producers [4]. Open field or standalone PV systems have been used in rural and remote areas where normal electricity supply may not be readily accessible [5]. In modern urban cities, most buildings are high-rise and the roof area would be very limited for stand-alone PV system installation [6]. In this building envelope type, the concept of building integrated photovoltaic (BIPV), which replaces part of the external walls with PV panels would be an appropriate alternative form of PV system [7]. Solar PV panels occupying a huge area for installation and the associated financial challenge could be best answered by space-saving technologies like BIPV installation [8]. Locally, a study on RE reported that PV technologies are potentially suitable for wide scale applications in Hong Kong [9].

Integration of PV systems with distribution networks (grid-connected) could reduce the maximum demand charge and energy losses [10]. However, because of high initial costs, large installation spaces required and limited output energy, PV applications are not popular in local building developments [11] and local data indicating the actual energy performance for design and evaluation are not sufficient [12]. The technical information provided for standard test conditions may never occur in practice [13]. On-site measurement is the most accurate method of obtaining reliable data and determining the performance of various designs under the actual operating environments for evaluation [14]. Systematically recorded meteorological readings and output energy data are essential to study the technical performance of a PV system [15]. Technical performance of a PV system as regards efficiency can be estimated based on the energy output and solar radiation. Life cycle assessment that considers all the energy flows

* Corresponding author. Tel.: +852 34427063; fax: +852 34420427.
E-mail address: bcdanny@cityu.edu.hk (D.H.W. Li).

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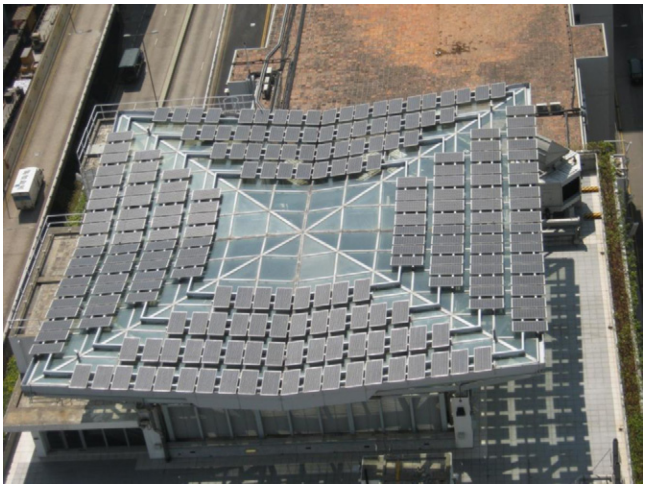

Fig. 1. The BIPV system.

associated with different production stages is an essential process to justify the sustainability and benefit of such systems [16,17]. The present 'state-of the-art' in consequential LCA is to identify the long-term change in power plant capacity and the changes in annual electricity demand affect the supply of electricity differently from one hour to another [18]. Financial, energy and environmental issues can be evaluated in terms of respectively monetary, energy and greenhouse-gas payback periods [19,20]. This paper studies a grid-connected BIPV system installed in an institutional building. Field measurement of energy output and meteorological data were systematically recorded and the corresponding efficiency was computed. The monetary payback period (MPBP), embodied energy payback period (EEPBP) and greenhouse-gas payback period (GPBP) of the PV system were calculated and analyzed. The characteristics of the findings and design implications are discussed. This on-site measurement contributes the most accurate method of obtaining reliable data for determining the performance of various designs under the actual operating environments for evaluation.

2. Site and system description

The institutional building is a purposely built 13-storey block located in the peripheral of an industrial zone in Hong Kong which is situated along the southern coast of China within the subtropical region, at latitude of 22.3N and longitude of 114.2E. The institution is surrounded by buildings in three cardinal orientations (i.e. N, S and W) and a highway on the east. The BIPV together with the structural supporting frames and glazed panels formed the integrated skylight system to provide solar converted electricity to the building and daylight to the atrium beneath.

2.1. BIPV system

In principle, the PV process converts solar energy into electricity. The PV equipment has no moving parts with a virtual silent operation and hence requires minimal maintenance. It generates electricity without producing emissions of greenhouse gases or pollutants which are the by-products to burning fossil fuels for energy production. The BIPV was placed on the roof and the aerial view of the panels is shown in Fig. 1. The panels were mounted at small inclination angles between 4° and 12° for preventing the accumulation of dust and rainwater on the surface. The system comprises 224 numbers of solar modules giving an area of 296 m^2. The peak power under standard test conditions for the whole system is 40 kW. The system is grid-connected such that continuous electricity supply to load can be guaranteed in case of a lengthy bad weather or system failure. No battery for power storage is required as another environmental conservation measures. Table 1 summarizes the technical specifications for the solar cells which are permanently laminated between special anti-reflective tempered glasses and backed by multiple layers of ethylene vinyl acetate (EVA) polymer for protection. These materials were bonded together under pressure and heated to form a tough laminate structure. This weather-proof package was sealed by a neoprene edge-gasket and supported by a rugged lightweight aluminum frame.

Table 1
Technical specifications of the solar cell.

Total solar power	40 kWp
Solar cell type	Mono-crystalline silicon
Number of modules SQ175PC	224
Number of modules in series	12 and 8
Number of parallel strings	18 and 1
Maximum power point MPP current (STC)	4.95 Apc
Maximum power point MPP voltage (STC)	35.4 Vpc
Open circuit voltage (STC)	44.6 Vpc
Power of one module SQ175PC	175 Wp
Module efficiency	13.3%
Outside dimension of one module	1623 mm × 813 mm × 40 mm
Weight of one module	18.2 kg

STC, standard test condition (i.e. cell temperature = 25 °C; solar irradiance = 1 kW/m^2 and air mass = 1.5).

2.2. Inverter

The 224 solar modules were configured to 18 (parallel) × 12 (series) and 1 (parallel) × 8 (series). Every 36 modules were connected to an inverter and the remaining 8 modules were connected to another inverter. Altogether, 7 inverters were employed. The DC power generated from the PV panels was converted to AC power by the inverters that were connected to a 63A TPN MCB Board. Such PV-module array is in line with the industrial practice. PV modules are the fundamental power conversion units. A single PV module has limited potential to provide power at high voltage or high current levels for normal load. Thus, PV modules are normally connected in series and in parallel in order to scale-up respectively the voltage and current to tailor the PV array output [21]. The inverters were equipped with power conditioning function to control the harmonics and output power factor with built-in isolation transformer to prevent direct current feeding into the gird. Besides, the maximum power point tracker (MPPT) was used to adjust the voltage of the PV generator to operate in its maximum power point. Anti-islanding device was engaged to disconnect the inverter automatically from the grid in case of grid de-energizing. The signals were logged by a computer package via RS 485 for the seven inverters and the data were fed to a computer workstation for reporting and analysis. The electricity generated was passed through the utilities company check meter before feeding into the grid.

3. Data measurement and analysis

On-site measurement is the most accurate method of obtaining reliable data for evaluating PV designs under the actual operating environments. The performance of a PV system is influenced considerably by a number of climatic variables including the solar radiation and ambient temperature. The amount of electricity generated strongly depends on the availability of the solar energy falling on the PV panels. Graphical representation is a simple and direct approach to analyze and interpret data. The frequency at a given input solar radiation and output energy provide the operational characteristic and performance for the BIPV system.