

Integrated photovoltaics as an element of building's envelope

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ABSTRACT

Using renewable energy sources (RES) in building sector is already an issue of major importance due to fuel overpricing, world population growth and residential energy consumption increment. Besides, the observance of protocol of Kyoto and European Commission's directive 2001/77/EC impose further application of RES in urban environment. Within this framework and as a part of a wider initiative to reduce energy consumption in buildings, construction companies are beginning to integrate photovoltaic (PV) systems into the roof or the facades of new or renovated structures. Building integrated photovoltaic (BIPV) systems, apart from generating electricity by utilizing solar radiation, are also installed as major construction material, substituting more expensive conventional materials.

1. INTRODUCTION

As a part of a wider international framework that intends to reduce national energy dependence on conventional fuels and deter environmental pollution and continuant global climate changes, more and more countries view distributed photovoltaic systems as power source with large potential for the future and are correspondingly starting to construct and operate BIPV systems on a large scale.

BIPV systems provide a reliable solution for electricity supply both in new and existing or planned buildings at places with or without electrical grid and possess main benefits over centralized grid connected PV plants or non-integrated systems:

- PV systems integrated into buildings can avoid the cost of land acquisition, fencing, access road and major support structures for the modules (Oliver and Jackson, 2001).
- BIPV systems can provide the function of protecting the building envelope from the weather, avoiding the use of other more expensive conventional cladding or roofing materials. The avoided cost of these materials is subtracted from the installation cost of BIPV improving their economics. However, in order to be effective, BIPV products should match the dimensions, structural properties, qualities, and life expectancy of the materials they displace.
- BIPV can enhance the aesthetic and architectural quality of building.
- BIPV produce electricity at the point of use avoiding transmission and distribution of electricity and the costs and losses associated with this. Regarding especially grid-connected systems, the building owner is also capable of obtaining significant revenues by selling the surplus electricity generated to the utility grid so that the high initial cost of BIPV will surely be considered as a financially beneficial and viable investment (Bakos et al., 2003).

Generally, a BIPV system is designed to serve more than one function. Hence, it is defined as a multi-functional building material. It can be used as exterior shading device or insulating roofing material or it can directly displace the exterior façade of the building:

- BIPV façade systems include laminated and patterned glass, spandrel glass panels, curtain wall glazing systems cladding systems and

awning systems (Fig. 1).

- Roofing systems include BIPV shingles, tiles, metal roofing, exterior insulation roof systems and atrium or laminated roof systems (Fig. 2).

The primary goal in a BIPV system layout is to maximize the amount of power produced via optimum array orientation, but this goal is tempered in the case of building design by considerations of construction costs, optimum building floor area, daylight control, thermal performance, cooling load and aesthetics. Hence, the issues of BIPV systems design and construction are not exclusively technical and the balance between them will vary greatly according to the circumstances of each project (climate, budget, client priorities, aesthetics, etc.) (NREL, 1995).

2. MULTI-FUNCTIONAL BIPV SYSTEMS

The economic value of a BIPV array would be optimized in a configuration that serves all four possible functions of a BIPV system (Byrne et al., 2001):

- As an energy supply technology delivering



Figure 1: BIPV façade system examples (EPIA 2004, Kurokawa 2001).



Figure 2: BIPV roofing system examples (EPIA 2004).

bulk energy (kWh).

- As an architectural element, reducing the materials cost of the building, while providing building services.
- As a buildings services technology offering energy demand management (primarily, peak shaving benefits).
- As an emergency power system (through the addition of a modest amount of storage).

The basic configuration of BIPV as building energy supply technology consists of a PV array connected via power conditioning equipment to the building's distribution panel. In this configuration, BIPV system operates as an electrical energy supply system, complementing the energy obtained from the grid and supplying the surplus energy generated to the grid.

A BIPV array can also serve as an architectural element containing both aesthetic and functional value. Such an application would ordinarily be most appropriate for consideration in the design of a new or renovated building. While "architectural" BIPV systems can be designed for rooftop or façade use, material cost savings are normally greatest in the case of façades.

BIPV system as an energy demand management devices require the addition of modest amounts of storage to the PV array, allowing the system to operate as a dispatchable peak-shaving technology.

The addition of an emergency power (EP) function to the energy demand management system is a means of further increase of the storage batteries bank. The economic benefit of adding an EP function to a BIPV peak-shaving system can be expressed as the avoided cost associated with the purchase and operation of a conventional EP system.

3. BENEFITS

3.1 BIPV System Value

The value of BIPV systems can directly affect the decision making process. These benefits can be identified and evaluated based on direct economic impact, indirect economic impact and qualitative value (IEA, 2002):

- Direct economic impact: A BIPV system is generally procured through a construction

budget. Electricity generated by the system creates for the building owner savings associated with construction material costs and electricity costs, enhancing power quality and reliability and providing tax credits.

- Indirect economic impact: Each building owner has a value related to strategic goals, business interests or organizational mission. With a multifunctional BIPV system, additional costs and benefits may accrue and may be hidden or not obvious, due to accounting methods and the directly and indirectly affected budgets. However, if an economic effect cannot be captured or understood by, a decision-maker, it is generally not included in an investment analysis.
- Qualitative value: Some benefits of BIPV systems are subjective and difficult to quan-

tify. For the building owner, a considerable value of a BIPV system may be associated with a positive image, public perception or impact on the build environment when the technology is installed. Table 1 summarises these values according to electrical, environmental, architectural and socio-economic aspects.

3.2 Thermal Benefits

The energy generated by the BIPV system can be also evaluated by the system's energy contribution to the building's thermal performance. The BIPV system can be designed according to the building's cooling, daylighting and heating loads, since it can provide shading, reduce cooling loads during summer, admit daylight and contribute to building's heating loads by producing, for example, heat when ambient air is vented behind the BIPV glass panels to cool the solar cells.

3.3 Electricity Benefits

The value of electricity generated by a BIPV system is determined by the amount of electricity consumed plus the value of surplus electricity generated. More specifically, the difference of the estimated baseline energy bill and the actual cost of the solar energy source determine the value of BIPV electricity generation to the building owner. Furthermore, building owner can be paid in retail electricity rates or utility avoided cost rates for surplus energy generated when the BIPV system is grid-connected, using dual or net metering respectively which accounts for the electricity produced by the BIPV system. However, in developed countries, there is already legal framework which defines a standard price (0,45-0,50 €/kWh in Greece) for surplus energy that is supplied to the grid by renewable energy sources such as BIPV systems.

Table 1: Summary of BIPV system qualitative benefits.

Categories	Potential values
Electrical	Peak generation and load matching value; reduction in demand for utility electricity; power in times of emergency; grid support for rural lines; reduced transmission and distribution losses; improved grid reliability and resilience
Environmental	Significant net energy generator over lifetime; reduced air emissions of particulates, heavy metals, CO ₂ , NO _x και SO _x resulting in greenhouse gases, reduced acid rain and lower smog levels; reduced impact of urban environment; less nuclear risks
Architectural	Substitute building component; multifunctional potential for insulation, water proofing, fire protection, wind protection, daylighting, shading; aesthetic appeal through color, transparency, non reflective surfaces; reduced building maintenance and roof replacements
Socio-economic	New industries, products and markets; local employment for installation and servicing; resource diversification; reduced fuel imports; deferment of large capital outlays for central generation plant or transmission and distribution line upgrades; potential for international cooperation and collaboration

4. COST OF BIPV SYSTEMS

The BIPV system cost depends on the type and size of system, on current PV technology, and on whether a custom product or standardized manufactured product is used. Table 2 summarizes the parameters which affect on the overall unit production cost of electricity generated by a BIPV system (Castro et al., 2005).

A comparison between the operational cost

Table 2: Parameters of BIPV electricity unit production cost.

Parameters	
Cost of conventional building materials	It is subtracted from the initial cost of a BIPV system
PV installation cost (5 – 7 €/Wp)	It includes PV modules (3 - 4 €/Wp), inverter, cables, batteries, transportation, labor, engineering, administration costs and taxes
Operational and maintenance costs	Periodic system checks. Clearing away any debris. Visual inspection of essential components. Possible replacement of faulty component.
Subsidies and tax exemptions	

per kWh of a BIPV system and the retail cost per kWh of grid electricity can indicate clearly whether an investment in a BIPV system would be economically profitable or not.

Through a validated simulation of a PV system integrated on the roof of an ordinary family house and a PV system integrated on the façade of an office/hotel building replacing glazing in Greece, the unit production cost was estimated at 0,19 €/kWh and 0,16 €/kWh respectively. The main reason for the obvious lower unit production cost in the case of the integrated PV system in the hotel/office building is the high cost of glazing that was substituted in the façade, which is subtracted from the total installation cost (Spanos and Duckers, 2004).

5. BIPV PROBLEMS AND RELIABILITY ISSUES

BIPV system design requires a thorough study about the reliability issues that can arise during system's operation resulting in its low yield. Furthermore, it requires extensive construction in order to avoid probable system's faulty installation. Table 3 summarizes the most important reliability issues of a BIPV system (Laukamp et al. 2000).

Moreover, BIPV systems face a number of barriers to the mainstream energy and building markets: High capital and associated financing, administration, architecture, communication, marketing and environment. Some barriers can

Table 3: Major BIPV system's reliability issues.

Reliability issues	
Poor performance	Inverter failures. Real power of a module below its name plate power. Partial shading of the generator by trees, other buildings and protruding building parts. Defects in the direct current installation causing interrupted strings.
Planning and design problems	Unsuitable string fuses and overvoltage protection devices. Unsuitable isolation switches between PV array and inverter. Faulty PV modules (broken glass, open circuits, discoloration).
Operational problems	Corrosion and defects in the solar generator mounting. Strong soiling of the PV modules.
Installation issues	Solar generator cabling not mechanically fastened. Lack of heat dissipation of string diodes. Loose terminal connections.

be overcome by assessing the energy and non-energy benefits of a BIPV power system, thus making it a cost-effective option even with current costs and energy prices. Table 4 presents the most significant commercialization problems of BIPV systems nowadays (Eiffert, 2003).

6. BIPV CASE STUDIES & APPLICATIONS

6.1 Lewis Center for Environmental Studies

The Oberlin College Lewis Center for Environmental Studies is a two-story, 1170 m² classroom and laboratory building (Fig. 3). The building was occupied in January 2000. The integrated PV system is 60 kW, 3-phase, grid-connected roof mounted system with no battery storage. The standoff array tilt follows the roof curvature, which varies from facing 5° north to 20° south. The system includes daylighting, natural ventilation and energy management system to optimize the performance of building mechanical and electrical devices. Actual performance data indicated that the BIPV system produced more power than was needed during 2 months and than more than 2/3 of the building's demands during additional 4 months. However,

Table 4: Commercialization barriers of BIPV systems.

Problem category	
High capital and associated financing	High installation cost. Cost gap between PV costs and acceptable market price. Few investments because of low profits. PV not competitive with fossil fuels. High investment risks. Subsidy procedures slow and variable.
Administration	Lack of appropriate national legal framework and economic regulations. Procedures for permits for BIPV unclear and slow.
Architecture	PV systems not fit for buildings. Optimal installation PV not compatible with buildings. Limited colors and sizes. Lack of guidelines for installing BIPV systems. High cost and uncertainty by lack of standards.
Communication	Lack of confidence and awareness of PV. No reliable, independent information source. Lack of experience and knowledge on PV technology, the markets and the building sector.
Marketing	Lack of trust among customers because of absence of business plans. Inadequate understanding of valuing PV.
Environment	High embodied energy in PV. PV made by toxic and hazardous materials.

issues associated with system's poor performance were arisen such as transformer stand-by losses, inverter faults and snow coverage (Hayter et al., 2002).

6.2 Bighorn Home Improvement Center

The Bighorn Home Improvement Center consists of a 1720 m² hardware store retail area and a 2120 m² indoor lumpyard and warehouse. An 8,88 kW, thin film, grid connected PV system is integrated into the standing seam metal roof (Fig. 3). The system includes daylighting, natural ventilation and energy management system to control the lights, the natural ventilation and the heating system. Actual performance data indicated that the BIPV system produced more



Figure 3: Oberlin College Lewis Center for Environmental Studies (left), Bighorn Home Improvement Center (right) (Hayter et al., 2002).

power than was needed during 6 months. However, problems such as PV module overheating due to insulated roof and mismatched inverter settings with the maximum power points of the BIPV system resulted occasionally in poor performance.

6.3 BIPV Applications in Greece

The first grid connected BIPV system in public building was installed into the façade of Chemical Engineering Department of Metsovion Polytechnic School in November 2002 (Fig 4). In June 2004 a 5,04 kW BIPV system was also installed onto the tilted roof of International Airport of Athens (Fig 4), which produce annually 7501,7 kWh (1500 kWh/Wp), whereas the annual output was predicted much lower at 1350-70 kWh/Wp. A 2,25 KWp BIPV system was installed experimentally in the roof of Kastoria Center for Environmental Studies replacing tiles and producing annually half of the building energy demands. Further considerable BIPV systems are installed onto the roof of Technological Museum of Thessaloniki and into facades of several apartment buildings in area of Athens (Fig. 4).



Figure 4: National Metsovion Polytechnic School (above left), International Airport of Athens (above right), Center for Environmental Studies (center left), Technological Museum of Thessaloniki (center right) and apartment buildings in area of Athens (below).

7. CONCLUSIONS

The market potential of BIPV systems is widely recognized as significant. Many utility companies and several developed countries have already adopted this technology to augment their infrastructure and electricity services network. The solar industry has demonstrated the viability of BIPV systems technology by installing thousands of successful systems around the world. However, further steps must be taken by countries and international organizations to introduce and commercialize BIPV systems in the build environment:

- Financing: Lowering overhead and labor costs; developing techniques to model costs and benefits, i.e., life cycling costing, lowering costs by bulk purchase.
- Administration: Implementing a long-term stable policy and a uniform legal framework; making simple subsidy arrangement; following strategies to interest customers; allowing grid access to private producers.
- Architecture: Developing PV products in wider colors and sizes that meet requirements of building elements; applying internationally agreed and certified standards.
- Communication: Applying valid design tools; giving more detailed information about PV products; distinguishing target groups according to their needs;
- Marketing: Promoting and distributing wanted PV products with guarantees and service that satisfy demands; developing marketing strategy;
- Environment: Producing PV products by not hazardous recyclable materials; reducing high embodied energy in PV.

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