CURRENT SCENARIO OF BUILDING-INTEGRATED PHOTOVOLTAICS (BIPVS)

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Abstract: -

The building-incorporated photovoltaics (BIPVs) are photovoltaic (PV) materials that are used to supplant traditional/conventional building materials that are being used in construction of building covering, for instance, the roof tiles, front windows, or veneers. Further, they represent a strong, versatile and eco-friendly means for attaining the goal of ever-increasing power demand for zero energy and zero emission buildings of the adjacent future. In this regard, BIPVs may offer an aesthetically pleasing, cost-effective and real-world solution, to integrate photovoltaic solar cells (BIPVs) reaping solar radiation to produce electricity along with climate protection of the buildings. This research work précises the current stage of the development in the Building-integrated Photovoltaic systems and the scope of future research in building integration of photovoltaics, incorporating the latest and innovational ideas and features of BIPVs which include BIPV tiles & modules, BIPV foils, and solar power cell glazing products.

Keywords: - Building-integrated photovoltaic; Eco-friendly; Zero energy; Zero emission; BIPVs; Solar cell; Recent development.

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1. INTRODUCTION

As it is one of the well-known facts that the world's energy demand is increasing like a rapid fire, this exponential increase in energy demand in the name of development and to raise the living standard of humanity, a stage has arrived where focus should be on renewable & non-polluting energy, along with high energy efficiency and cost effectiveness. Buildings should be designed on zero energy and zero emission concept. In order to make any building complied to the idea/concept of zero energy and zero emission, it is required to crop its energy demands from its surroundings itself, where solar energy from the sun seems to be one of the major available options. BIPV systems are the energy systems where solar cells are embedded within the climate coverings of buildings and these solar cells exploit solar radiation to generate electricity at justified running/maintenance cost, and represent a stronger and adaptable means for attaining the goals of clean, eco-friendly and renewable energy w.r.t. aesthetical, cost-effective and real-world technical solutions.

BIPV systems can offer dual savings i.e., they reduce materials as well as electricity expenses. Also, they lead to lesser usage of fossil fuels and lower emission of ozone-depleting gases (CFCs etc.), and also enhance architectural attractiveness of the building. Further, the building-integrated photovoltaic (BIPV) systems may replace the traditionally used building materials and systems within the climate casing of buildings, for instance, the roofs, skylights and frontages. BIPV frameworks should be considered as a utilitarian part of the building structure as they are structurally coordinated into the building's configuration [3]. Hence, the BIPVs serve the dual functionality of being a building envelope material and also work as a power generator [4].

This research work essentially concludes the current scenario of the developments of BIPVs, including the BIPV tiles, foils, modules and solar (PV) cell glazing products, but we have also focused on building-attached photovoltaic (BAPV) systems because of their similarity with BIPVs. Building-applied photovoltaics (BAPV) are sometimes referred as photovoltaics that are fitted into the building envelope only after construction work of the building is complete. For auxiliary overview and embellishments including some possible research prospects and conduits for the future BIPVs, reference [5] may be referred.

2. Building integration process of photovoltaic (PV) cells

First of all, the probable spaces within the building envelope have to be recognized for the integration of PV cells/modules. The building integration of photovoltaic (PV) cells are basically done on slanted roofs, level roofs, fronts and solar shielding systems. Building-integrated photovoltaic cells may be installed above the building envelope itself or onto the existing conventional rooftop or wall covering systems. These systems replace the building's outer envelope membrane, therefore serving simultaneously as a climate screen as well as a power source by generating electricity. Hence, BIPVs provide savings in materials and reduce labor as well, further reduce the electricity expenses. However, the Building-integrated photovoltaics (BIPVs) function as the climate shelter screens which requires to have satisfactory or strict necessities of airtightness, toughness and durability.

Many aspects have to be taken and evaluated w.r.t. the integration of photovoltaic cells into the outer casing of building envelope. One of the important aspect is to ensure proper air gap below the PV cells in order to provide sufficient air flow which will reduce the temperature of the solar PV cells, because at high temperature the efficiency of the solar cells decreases, specifically for mono-crystalline and poly-crystalline silicon (Si) cells. Other aspect that has to be considered is the leaning of the BIPVs, for both existing and new buildings, as PV cells essentially need to follow the inclination of roof (or the wall) for its proper integration in the buildings. Also the geographical position, orientation towards the sun and exposure area are yet another factors to be considered during integration process of the BIPV systems. Some BIPV companies also offer a range of dummy modules to deliver more aesthetical and reliable appearance of the rooftops and frontages.

Henceforth, it is concluded that BIPVs have to fulfil all the necessities, w.r.t. different properties, of the building's envelope membranes which they are substituting. Along the above explained factors, other building physical subjects like e.g. moisture and heat transportation in the building's envelope are also important and should be accounted for. Solar cell (PV) glazing products also offer a good solution for using the fenestration w.r.t. sunshine, solar-heat gain, solar shading, and finally solar energy gain by transforming solar radiation into useful electrical energy.

3. BIPV's architectural traits

BIPV systems serve not only to create architectural appeal, they also offer savings in building materials that would otherwise be used and reduced electricity costs. Along with this, these systems will protect against the weather and will be a source of clean, eco-friendly and renewable energy. In view of availability, numerous options for innovative architectural design are available with us provided by leading manufacturers of BIPVs, which are also aesthetically soothing. BIPVs may also be utilized as screening devices and also give a solution for semi-transparent elements of fenestration [10].

Further, silicon tiles can be used to construct a building-integrated photovoltaic roof which may appear very much similar to a standard/conventional tiled roof, whereas semi-transparent modules can also be used in frontages or on the glass ceilings to craft different soothing visual effects. Some want BIPV roofs to give clear visual impression and is preferred by most of the architects, while other people want the BIPV roofs to appear very much similar to a traditional/conventional roof. More info about building integration of photovoltaic power systems and building integration of BIPVs in particular, may be found in references [3] [7].

4. Test methods and BIPV quality standards

Assessment/quality inspection of BIPVs involve several mathematical deciding factors, e.g. solar cell efficiency

$$\eta = P_{\max}/(\Phi A)$$

where Φ is the input solar radiation in W/m^2 ;

A is the surface area of photovoltaic cell in m^2 ;

$P_{\max}$ is the power at maximum power point (MPPT) in Watt-peak (Wp); V_{oc} is the open circuit potential or voltage in volt (V);

I_{sc} is the short circuit electrical current in Amp (A);

Also,

$$\text{Fill factor(FF)} = P_{\max}/(V_{oc}I_{sc}) = (VI)_{\max}/(V_{oc}I_{sc}),$$

The fill factor (FF), is a parameter which when combined with V_{oc} and I_{sc} , governs the amount of power obtainable from a solar photovoltaic (PV) cell. Mathematically, it may be defined as the ratio of the maximum power obtainable from the photovoltaic solar cell to the product of V_{oc} and I_{sc} . The significance of fill factor is that it measures the square-ness of the solar cell in terms of the area of the largest possible rectangle which can accommodate into the I-V characteristic curve of the photovoltaic cell. The graph representing the fill factor is given below.

The values of different parameters of BIPV as claimed by solar cell manufacturers are mainly obtained by the quality tests done at standard test conditions (STC).

The binding quality standards for Building-Integrated Photovoltaic (BIPV) modules are the standards: EN-61646 "Thin-film BIPV (Building-integrated Photovoltaic) modules: designer qualifications and type of approval" [8], EN-61215-2005 "Silicon (Si) crystalline terrestrial photovoltaic (PV) module: Designer qualifications and type of approval" [9], EN-61730-1 "photovoltaic (PV) module's safety qualifications – Part 1" [10], EN-61730-2 "Photovoltaic (PV) modules: design & safety qualifications" [10] & UL-1703 "UL-standards for safety of flat-plate Photovoltaic (PV) modules & panels" [11]. The above mentioned standards may be referred for further information.

5. Current scenario of BIPVs

5.1. BIPV classification

A wide range of BIPV products are available in the market, which may be classified in several different ways depending upon the criteria of characterization. This work of categorization is mainly dependent on the product specifications from the companies and for what other materials, the products are customized to be combined with. Based on these two important factors, the building-integrated photovoltaic products or systems may be classified as follows:

- (i) BIPV foil products
- (ii) BIPV tile products
- (iii) BIPV module products
- (iv) Solar cell (PV) glazing products

Other than above classifications of BIPV products, one more related category should be discussed i.e. the Building-Attached Photovoltaic (BAPV) products, as BAPVs are very much similar to the BIPV systems and sometimes it may be difficult to differentiate them:

- (v) BAPV products

The only major difference between the two BIPVs and BAPVs is that Building-attached photovoltaic (BAPV) products

are observed as attachments to the buildings itself, hence they are not directly linked to building structure's functional aspects [3]. That is, BAPVs are different from BIPVs, because the BAPVs are not integrated into the building's envelope as like BIPVs do, thus they do not replace the traditional/conventional building parts. Specifically, BAPVs may be referred as the attachments to the buildings, which is done after the construction work is finished.

Some of the BIPV products have extensive range of properties and features, thus it becomes more difficult to classify them. However, in some of the cases it might be somewhat difficult to even decide whether a PV product should be considered as a BIPV product or BAPV product, all because of deficiency of information and uncertainty about how the product is going to be mounted. For detailed appraisal of the BIPV products or systems, including the references and contact-info, reference [5] may be referred.

5.2. BIPV foil products

These have an added advantage of the flexibility and are lightweight products, which are advantageous w.r.t easier & faster installation and prevailing weight constraints for roofs. In these foil products the PV cells are usually made from thin-film cells to uphold the flexibility feature in the foil along with their efficiency at elevated temperatures. They are of great use for the non-ventilated rooftop solutions. Unfortunately, at present there are only a few manufacturers of BIPV foil products available in the market who offer real-world weather tight solutions. Some BIPV foil products available to consumer in the market are given below in **Table 1**. They specifically have a low fill factor because of the lower efficiency and the large solar cell resistances of thin-film cells. However, as an advantage it is always possible to alter the degree of inclination of the BIPV foil product to provide flexibility in their use.

Table 1. Specification sheet for few BIPV foil products available in the global market [5].

Manufacturer	Product Name	efficiency η (%)	V _{oc} (Volt)	I _{sc} (Amp)	P _{max} (Watt)	Fill factor (FF)	Area (mm ²)	P _{max} /Area (W/m ²)
Alwitra GmbH & Corporation	valonVolar- 408		138.6	5.1	408.0/module	0.58	1550 x 6000	42.90
	EvalonV Solar-136		46.2	5.1	136.0/module	0.58	1050 x 3360	38.50

5.3. BIPV tile products

Basically, BIPV tile products are the roofing tiles which may shield the entire rooftop or a part of the rooftop and act as the replacement for conventional/traditional tiles used on the rooftops. In view of their structure, they are side-by-side arranged PV modules with same physical look and properties like of standard roof tiles and act as a substitute to the traditional roof tiles, thus enables the easy retro-fitting of roofs. The tile shape and cell type differs with the manufacturer. Few of the tile products look like curved ceramic tiles but they have a drawback of lesser effective area because of its curvy surface, but on the other side they are more aesthetic and hence preferred for looks and decorative finishing. Some examples of BIPV tile products available to the customer in the market are given below in **Table 2**.

Table 2. Specification sheet of few BIPV tile products available in the global market [5].

Manufacturer	Product Name	efficiency η (%)	V _{oc} (Volt)	I _{sc} (Amp)	P _{max} (Watt)	Fill factor (FF)	Area (mm ²)	P _{max} /Area (W/m ²)
SRS Energy	Solé Powertile		6.30	4.6	15.75/module	0.54	868 x 457.2	39.70
Solardachstein	STEPdesign		23.75	2.40	1.36/cell	0.76	100 x 100 8 units	136
Solar Century	C-21e Tile	20/cell	12.0	5.55	52/module	0.78	1221 x 420	101.50
Lumeta	Solar Flat Tile		7.41	5.20	28/module	0.73	432 x 905	71.60

The BIPV tile products from top manufacturers Solardachstein, Solar Century and Lumeta provide the highest FF (fill factors) which indicates their high efficiency. In fact, Solar Century offers an efficiency of 20 percent/cell for their C-21e Tile and is more area effective. Further, the available design concept of the of the manufacturers like Solé Powertile and the STEPdesign is very much similar to the standard roof tiles, hence, they may replace several standard roof tiles. But, in these the PV module has an integrated panel of monocrystalline or polycrystalline cells. i.e., portions of the modules are not externally covered with PV cells, hence the area efficiency is low. The C-21e Tile from Solar Century has more active area than the any other products since monocrystalline Si (Silicon) cells shield the complete module area, and has compatibility with a diverse range of tiles and slates. Solé Powertile from SRS-Energy has skeleton very much similar to standard rooftop tiles.

5.4. BIPV module products

The BIPV modules are the solar products that look very much similar to traditional/conventional photovoltaic modules. But in case of BIPV modules, we have an advantage of having dual functionality i.e. together with electricity generation, they also provide the weather tight solutions. There are two types of BIPV module products, one which may replace several different types of roofing materials i.e. they are not manufacturer specific while second includes those which may fit only with a specific roof solution made by its own manufacturer. Further, the mounting systems of the BIPV modules makes their installation easier and hassle free. There are variety of products in the market out of which some are promoted as BIPV products irrespective of the fact that they do not function as weather skins, while other Building-Integrated Photovoltaic (BIPV) products do not provide any information about how they have to be mounted which leads to obscurity whether they are BIPVs or BAPVs. Some of the BIPV module products available in the market are given below in **Table 3**.

Table 3: Specification sheet of few BIPV module products available in the global market [5].

Manufacturer	Product Name	efficiency η (%)	Voc (Volt)	Isc (Amp)	Pmax (Watt)	Fill factor (FF)	Area (mm ²)	max/ Area (W/m ²)
Abakus Solar- AG	Peak-on P235-60	14.60	37.21	8.48	235	0.74	1630 x 1000	144.20
Creaton-AG	Creaton-Solesia		13.86	8.46	90/module	0.77	1778 x 355	142.60
Suntech	MSZ-190JD		45.20	5.62	190/module	0.75	1641 x 834.50	139
Solar Century	C-21e slate	20/cell	12.0	5.55	52	0.78	1174 x 318	139.31

5.5. Solar cell (PV) glazing products

Building-Integrated photovoltaic products when used as solar cell (PV) glazing products offer abundant variety of choices for building windows, tiled or glassed frontages and roofing. Different transparencies and colors can provide different aesthetic results. Some of the solar cell (PV) glazing product available to the customer in the market are given below in **Table 4**. The solar cell (PV) glazing modules serve dual functions i.e. they transmit daylight and also serve as water and sun protection inside the building. The optimum gap between the solar cells is normally 3 - 50 mm in solar cell (PV) glazing products which depends on desired transparency and the amount of electricity to be produced. The available gap between the solar cells transmits diffused sunlight in the daytime. Therefore, both natural lighting and shading are provided along with electricity production.

The solar cell (PV) glazing product's manufacturers generally provide customized products about the shape, cell material, color and different transparency level, i.e. the available gap between the cells.

Generally, the transparency of the solar cells (PVs) falls in the range of 16 % to 41 % for different Vidur solar models, while it has value of 25 % for the Abakus Solar-AG Peak in his P210-60 item model. The distinctive models from Sapa Building System utilizes either formless, polycrystalline or monocrystalline cells with various cell detachments.

Table 4. Specification sheet of few solar cell (PV) glazing products available in the global market [5].

Manufacturer	Product Name	efficiency η (%)	Voc (Volt)	Isc (Amp)	Pmax (Watt)	Fill factor (FF)	Area (mm ²)	max/ Area (W/m ²)
Vidur solar	FV-VS16 C36-P120	21.60	7.63				1600 x 720	
Glaswerke Arnold GmbH & Corporation	Voltarlux-ASI-TMono 4-fach		93	1.97	100/module	0.55	2358 x 1027	41.3
Schott Solar	ASI-THRU-4IO	6.0	111	2.21	189	0.77	1123 x 2620	64.72
Sapa-integrated Building System	Amorphous silicon(Si) thin film	5.0/cell			32/ cell		576 x 976 /cell	50
	Poly-crystalline	16.0/cell			1.46-3.85 /cell		156 x 156 /cell	120
	Mono-crystalline Highly efficient	22.0/cell			2.91-3.11 /cell		125 x 125 /cell	155

5.6. BAPV products

The Building Attached Photovoltaics (BAPVs) are the products that add on rather than integrated in the rooftop or frontage like BIPV products. They are extra attachments to the building and installed after the construction of building is completed. The BAPV solar products are not the main focus of this research work, but because of their similarities with BIPV products, it would be more interesting to look briefly at some of them. The Uni-Solar laminate (BAPV) available in the market have good flexibility, thus makes it easier to join with other building materials. Some other examples of BAPV products available to the customer in the market are given below in **Table 5**.

Table 5. Specification sheet of few of the BAPV products available in the global market [5].

Manufacturer	Product Name	efficiency η (%)	V _{oc} (Volt)	I _{sc} (Amp)	P _{max} (Watt)	Fill factor (FF)	Area (mm ²)	P _{max} /Area (W/m ²)
Hauptsitz	SunPower 220 Solar Panel	17.70	48.60	5.75			1559 x 798	
Uni-Solar	PVL-68		23.10	5.10	68/module	0.58	2849 x 394	60.60
	PVL-144		46.20	5.30	144/module	0.59	5486 x 394	66.60
Isofoton	ISF-240	14.50	37.10	8.45	240	0.77	1667 x 994	144.80

6. Economical aspects of BIPVs

As per the report of consulting firm Nano-Markets, New York [12], the global market for BIPVs is estimated to grow from \$1.8·10⁹ in 2009, to \$8.7·10⁹ in 2016. Further, Nano-Markets state that Copper Indium Gallium Selenide solar power cells will account for 17 % of the BIPV market in 2016 and polysilicon-based BIPVs will drop from 75 % of the market to 33 % by 2016 in terms of volume [12]. As PV panels require a large installation area, the associated financial challenge may be best countered by space-saving technologies like BIPVs [13]. BIPV systems are cheaper than other traditional/conventional PV systems that need separate and dedicated mounting systems. Further, Integration of photovoltaic products into building parts such as rooftops, windows, sunshades and glassed frontages gives the opportunity of cost saving by substituting common building materials with BIPVs at peripheral costs [6]. When BIPVs used as a covering material are compared to steel, glass or other more traditional/conventional covering materials, they seem to be much economical because of their low running and maintenance cost, but installing BIPV products adds a marginal extra cost of 2-5 % of the complete construction costs of a commercial building which later on gets balanced by the lower running and maintenance cost [14]. Also, this marginal installation and operation cost of the BIPV products/systems might be minimized by selling the surplus electricity to a regional power distribution company and may become a profit business [15].

Meanwhile, the price of a PV system is on decline with the improvement of technology advancement and increasing cut-throat competition in the global market, which has resulted into a lesser price per kW installed PV system [16], which is a vital part of the development for making installation and building integration of PV modules more profitable without government subsidies. To work out the energy payback time, the embodied energy of the system should be calculable [15]. For detailed knowledge of the energy-payback time reference [17] may be referred. Research and development work in the area of photovoltaic (PV) cells & modules and improvement/advancements in their technologies may have an even stronger impact on the coming future of BIPVs.

7. Conclusions

Today, the existing building-integrated photovoltaic products in the market offer an extensive range of integration of photovoltaic (PV) products or systems into buildings and their roofing & frontages. The research and development work is continued in both PV and BIPV materials and advancement in technologies will definitely produce better BIPV solutions along with good cost economics in the adjacent future. The increased efficiency of solar cell, reduction in production costs and improved building integration will bang the coming future of solar BIPVs & BAPVs. Further, there is a need of new and innovative solutions in the field of BIPVs which may cut costs and increase efficiency of BIPV products.

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References

- [1] Dr. J.P. Kesari. Empowering India with Green Energy Technology, paper presented in 53rd National Convention of Indian Institution of Industrial Engineering and National conference on India as a Technology Hub, (Dec. 16-17), 2011.
- [2] Kesari J.P. Solar Thermal Power Generation in India: An overview of recent policies under National Solar Mission, Proceedings of the National Conference on Management of Technologies for Advancing Rural India, SDCE at

Muzaffarnagarfeb.(5-6), 2011.

- [3] Y. Huang,Z. Wu,C. Peng, Building-integrated photovoltaics(BIPVs) in architectural design in China, *Energy and Buildings*43 (2011) 3592–3598.
- [4] S. Strong, Building-Integrated Photovoltaics (BIPVs), Whole Building Design Guide, <<http://www.wbdg.org/resources/bipv.php>>, June 9, 2010.
- [5] B.P. Jelle, H.D. Røkenesand C. Breivik, BIPVs: A state-of-the-art review and futurere search opportunities, *Solar Energy Materials and Solar Cells*, doi: 10.1016/j.solmat.2011.12.016, in press, 2012.
- [6] T.K. Mallick, P.C. Eames, B. Norton,S.J. McCormack,M.J. Huang,Y.G. Yohanis and J.D. Mondol,Enhancing theperformance of BIPVs, *Solar Energy* 85 (2011) 1629–1664.
- [7] A.G. Hestnes, Building-integration of solar energy systems, *Solar Energy* 67 (2000) 181–187.
- [8] European Committee for Electro-TechnicalStandardization, Thin-film Terrestrial Photovoltaic (PV) Modules – DesignQualification and Type Approval, EN 61646, European Standard, 2008.
- [9] European Committee for Electro-TechnicalStandardization, Crystalline Silicon Terrestrial Photovoltaic (PV) Modules – DesignQualification and Type Approval, EN 61215, European Standard, 2005.
- [10] European Committee for Electro-TechnicalStandardization, Photovoltaic (PV) Module Safety Qualification – Part 1& Part 2: Requirements for Construction, EN 61730-1&EN 61730-2, European Standard, 2007.
- [11] Underwriters Laboratories Inc., UL Standard for Safety Flat-Plate Photovoltaic Modules and Panels, UL 1703, 2002.
- [12] Dow,R. Coons: Solar shingles could generate \$5 billion by 2015, *Chemical Week* 171 (2009) 9.
- [13] S.N. Mandal,D. Paul, S.R. Bhadra and D. Mukherjee Chaudhuri, Optimisation of significant insolation distributionparameters – A new approach towards BIPV system design, *Renewable Energy* 35 (2010) 2182–2191.
- [14] P. Eiffert, Guidelines for the economic evaluation of building-integrated photovoltaic (BIPV) power systems, NREL/TP-550-31977,2003.
- [15] IEA-PVPS, Grid-connected power systems: Summary of IEA/PVPS Task V activities from 1993 to 1998, T5-03, 1999.
- [16] M. Elnimeiriand H. Sozer, Critical factors in reducing the cost of building-integrated photovoltaic (BIPV) systems, *Architectural Science Review*-50 (2007) 115–121.
- [17] G.P. Hammond, C.I. Jones, A.B. Winnett andH.A. Harajli, Whole systems appraisal of a UK building-integratedphotovoltaic (BIPV) system: Energy, environmental, and economic evaluations, *Energy Policy*- 40 (2012) 219–230.