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MARK THROWER MANAGING EDITOR

SERIES **15** | MODULE **09** | **PHOTOVOLTAICS**

Turning sunlight into electricity

By Joe McClelland, senior energy consultant

The first known use of the term photovoltaic was circa 1889, according to the International Scientific Vocabulary's confirmation of its origin and etymology.

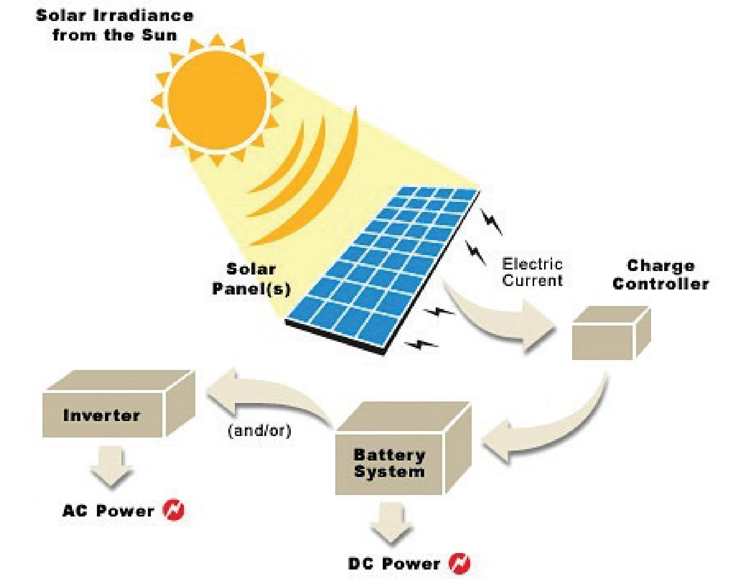
The definition of photovoltaic is: “of, relating to, or utilising the generation of a voltage when radiant energy falls on the boundary between dissimilar substances (such as two different semiconductors).”

The voltaic part of photovoltaic comes from the name of Alessandro Volta, inventor of the electric battery. Unlike photoelectric cells which use electricity for certain small tasks, photovoltaic cells actually produce electricity. Solar cells, the standard type of photovoltaic cells (often called simply photocells), operate without chemicals and with no moving parts to create energy directly from sunlight. Much research is now being done on creating an alternative technology—solar film, which could be stuck onto almost any surface, or even sprayed on.

Photovoltaic (PV) cells, convert sunlight directly into electricity. PV gets its name from the process of converting light (photons) to electricity (voltage), which is called the ‘PV effect’. The PV effect was discovered in 1954, when scientists at Bell Telephone discovered that silicon (an element found in sand) created an electric charge when exposed to sunlight. Soon solar cells were being used to power space satellites and smaller items like calculators and watches.

Silicon the most efficient

Traditional solar cells are made from silicon, are usually flat-plate, and are generally the most efficient. Second-generation solar cells are called thin-film solar cells because they are made from amorphous silicon or non-silicon materials such as cadmium telluride. Thin film solar cells use layers of semiconductor materials only a few micrometers thick. Because of their flexibility, thin film solar cells can double as rooftop shingles and tiles, building facades, or the glazing for skylights.



How a photovoltaic system works

Third-generation solar cells are being made from a variety of new materials besides silicon, including solar inks using conventional printing press technologies, solar dyes, and conductive plastics. Some new solar cells use plastic lenses or mirrors to concentrate sunlight onto a very small piece of high efficiency PV material. The PV material is more expensive, but because so little is needed, these systems are becoming cost effective for use by utilities and industry. However, because the lenses must be pointed at the sun, the use of concentrating collectors is limited to the sunniest parts of the world.

PV modules and arrays are just one part of a PV system. Systems also include mounting structures that point panels toward the sun, along with the components that take the direct-current (DC) electricity produced by modules and convert it to the alternating-current (AC) electricity used to power all of the appliances in your home.

Solar photovoltaic modules are where the electricity gets generated, but are only one of the many parts in a complete photovoltaic (PV) system. In order for the generated electricity to be useful in the built environment, a number of other technologies must be in place.

PV arrays must be mounted on a stable, durable structure that can support the array and withstand wind, rain, hail, and corrosion over decades. These structures tilt the PV array at a fixed angle determined by the local latitude, orientation of the structure, and electrical load requirements. To obtain the highest annual energy output, modules in the northern hemisphere are pointed due south and inclined at an angle equal to the local latitude. Rack mounting is currently the

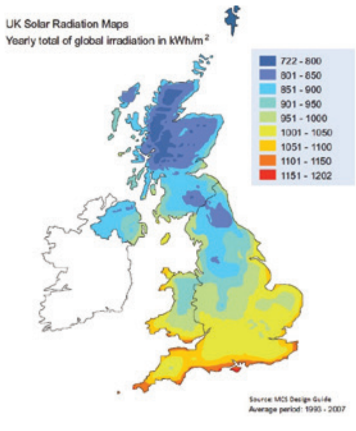
Produced in Association with energy institute most common method because it is robust, versatile, and easy to construct and install. More sophisticated and less expensive methods continue to be developed.

For PV arrays mounted on the ground, tracking mechanisms automatically move panels to follow the sun across the sky, which provides more energy and higher returns on investment. Single-axis trackers are typically designed to track the sun from east to west. Two-axis trackers allow for modules to remain pointed directly at the sun throughout the day. Naturally, tracking involves more up-front costs and sophisticated systems are more expensive and require more maintenance. As systems have improved, the cost-benefit analysis increasingly favours tracking for ground-mounted systems.

Inverters are used to convert the direct current (DC) electricity generated by solar photovoltaic modules into alternating current (AC) electricity, which is used for local transmission of electricity, as well as most appliances in our homes and in industry. PV systems either have one inverter that converts the electricity generated by all of the modules, or micro inverters that are attached to each individual module. A single inverter is generally less expensive and can be more easily cooled and serviced when needed. The micro inverter allows for independent operation of each panel, which is useful if some modules might be shaded, for example. It is expected that inverters will need to be replaced at least once in the 25-year lifetime of a PV array.

Advanced inverters, or "smart inverters," allow for two-way communication between the inverter and the electrical utility. This can help balance supply and demand either automatically or via remote communication with utility operators. Allowing utilities to have this insight into (and possible control of) supply and demand allows them to reduce costs, ensure grid stability, and reduce the likelihood of power outages.

Batteries allow for the storage of solar photovoltaic energy, so we can use it to power our homes at night or when weather elements keep sunlight from reaching PV panels. Not only can they be used in homes, but batteries also are playing an increasingly important role for utilities. As customers feed solar energy back into the grid, batteries can store it so it can be returned to customers at a later time. The increased use of batteries will help modernise and stabilise the electricity grid.



Global energy balance

The potential threat of global climate change, increasing energy demand of the developing world, and inevitably, although not rapidly, diminishing fossil fuel resources, have made sustainable energy supply a planetary issue that has to be addressed by every sector of human life. At the same time buildings continue to play a significant role in the global energy balance. Typically, they account for some 20-30 per cent of the total primary energy requirements of industrialised countries. With increasing awareness of the ecological consequences of energy consumption, the need for energy- and environment-conscious building design has become more and more pressing.

The building designer already has a number of sustainable technologies to choose from: premium thermal insulation, advanced heating, ventilation and air conditioning (HVAC) equipment, passive solar architecture featuring climate conscious building orientation and advanced glazing and daylighting options; active solar thermal technologies for space heating and domestic hot water; and energy efficient lighting and appliances. All these measures can and already have significantly reduced especially the thermal energy requirements of buildings. This in turn has increased the share of electricity in the energy balance of the building sector.

Until recently it was not feasible to go beyond the energy-conscious building design from merely saving to actually producing high value energy and sharing it with the whole society.

During four decades of photovoltaic activity the devices originally used in space technology have gradually found their way into numerous applications. The state-of-the-art photovoltaic technology today can be characterised as follows:

- PV modules are technically well proven with an expected service time of at least 30 years;
- PV systems have successfully been used in thousands of small and large applications;
- PV is a modular technology and can be employed for power generation from milliwatt to megawatt facilitating dispersed power generation in contrast to large central stations;
- PV electricity is a viable and cost-effective option in many remote site applications where the cost of grid extension or maintenance of conventional power supply systems would be prohibitive; and
- PV technology is universal: the PV modules feature a "linear" response to solar radiation and therefore may be mass produced and shipped world-wide.

Although the photovoltaics sector has the technical potential of becoming a major clean energy source of the future, it is not yet economically competitive in bulk power generation. Instead, it finds its practical applications in smaller-scale innovative "niche" markets like consumer products, remote telecommunication stations, and off-the-grid dwellings. However, due to rapid technological improvements and the pronounced need for sustainable energy solutions, PV in buildings, also connected to the utility grid, now shows promise of becoming more than just another niche market.

Traditionally, PV modules or PV arrays have been mounted on special support structures. However, they can also be mounted on buildings, or even be made an integral part of the building envelope thus creating a natural on- site link between the supply and demand of electricity. Through the use of photovoltaic the consumption of power plant based electricity may be significantly reduced. The buildings may even be turned into small distributed net electricity producers and, as such, offer increasing benefits to all.

No extra land requirements

From an architectural, technical and financial point of view, PV in buildings today:

- does not require any extra land area and can be utilized also in densely populated areas;
- does not require any additional infrastructure installations;
- can provide electricity during peak times and thus reduce the Utility's peak delivery requirements;
- may reduce transmission and distribution losses;
- may cover all or a significant part of the electricity consumption of the corresponding building;
- may replace conventional building materials and thus serve a dual role which enhances pay back considerations;
- can provide an improved aesthetic appearance in an innovative way;
- can be integrated with the maintenance, control and operation of the other installations and systems in the building; and
- can provide reduced planning costs;

Once put in the building context, photovoltaics should not be viewed only from the energy production point of view. Because of the physical characteristics of the PV module itself, these components can be regarded as multifunctional building elements that provide both shelter and power.

Being a mixture of technology, architecture and social behaviour, PV in buildings eludes unambiguous evaluation of its cost-effectiveness and market potential. To a large extent, the value of the concept remains to be assessed on a case-by-case basis given the economical, technological, architectural, social and institutional boundaries of the project under consideration.

The photovoltaic community may have great visions of the future, but PV in buildings is already an option for today with numerous successful examples. Building design is an integral process and photovoltaic technology adds to the choices available for the energy-conscious designer. It is up to the designer to weigh the pros and cons of the various technologies in each individual project, and make the choice. In short, photovoltaics is worth considering:

- if the building has access to solar radiation;
- if innovative design options are preferred; and
- if the building is or will be energy-efficient by design.

Although an inherently elegant concept, photovoltaics in buildings is not turned into appealing architecture and sound engineering without the concerted professional efforts of several disciplines. Only by working closely together, can engineers and architects combine technology and architecture in a way that may

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revolutionize our understanding of both energy and buildings.

Installation of systems

Any PV system must comply with Health and Safety Requirements, BS 7671, and other relevant standards and Codes of Practice. Much of the content of this guide is drawn from such requirements. While many UK standards apply in general terms, at the time of writing there is still relatively little which specifically relates to a PV installation. However, there are two documents which specifically relate to the installation of these systems that are of particular relevance:

- Engineering Recommendation G83/1 (2003) – Recommendations for the connection of small scale embedded generators (up to 16A per phase) in parallel with public low voltage distribution networks,
- IEE Guidance Note 7 to BS 7671 - Special Locations, Section 12 Solar Photovoltaic (PV) Power Supply Systems (ISBN 0 85296 995 3, 2003)

A mains-connected PV installation generates electricity synchronised with the electricity supply. Installers are obliged to liaise with the relevant Distribution Network Operator (DNO) in the following manner:

- Single installation covered by G83/1 – notification at or before day of commissioning followed by G83/1 paperwork (G83/1 appendix 3) within 30 days; and
- Multiple installation covered by G83/1 – application to proceed (G83/1 appendix 2).

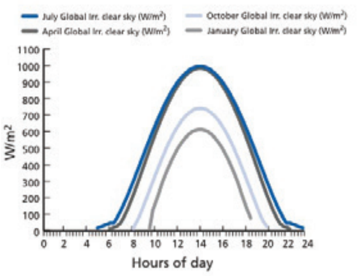
It is common practice for an inverter power to be less than the PV array rating and safety considerations with respect to sizing an inverter must be addressed.

However, also to be considered is the system performance. For example, a 1kWp array connected to a 1.5kW inverter may be safe but not energy efficient – with the UK climate, the inverter will be operating for much of the time at less than the 1kWp rating of the array and consequently at a poor point on the inverter efficiency curve depending on the inverter (inverters are typically less efficient at low power levels).

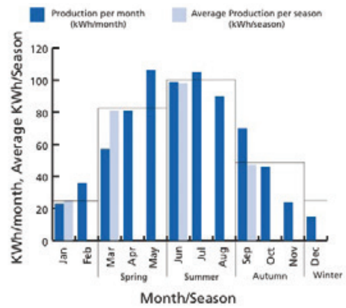
PV array: inverter ratios from 1:1 to 1:0.8 are commonly applied in the UK, though in certain circumstances and depending on the inverter used, ratios outside this are sometimes utilised (NB: Inverter power is taken to be maximum steady state AC power output).

Inverter mpp range - An inverter must be able to safely withstand a

Graphs illustrating daily insolation curves and the monthly and seasonal trend in photovoltaic system performance



Example average daily isolation curves: Manchester, 300 Inclination, due South. Ref: European Joint Research Centre, http://re.jrc.cec.eu.int/ pvgis/pv/ PVGIS©European Communities, 2002-2006



Example average kWh electricity generation bar chart: Manchester, 30° Inclination, due South, 750kWh/yr Ref: European Joint Research Centre, http://re.jrc.cec.eu.int/ pvgis/pv/ PVGIS©European Communities, 2002-2006

maximum array voltage and current. However, when choosing the most appropriate inverter, for inverter performance purposes and when considering the matching of an array to the mpp range of an inverter, an assessment can be made as to whether a narrower temperature band (e.g. -10 °C to 70°C) maybe acceptable and appropriate for that particular site.

Output of a PV system

The output of a PV system depends on many factors such as orientation, pitch, shading and geographical location.

Estimating exact annual performance of a grid connected PV system is difficult, however as a rule of thumb - a south facing, inclined plane, unshaded array in the UK can be expected to generate on average 750kWh per kW installed per year. Please note that this can be a conservative figure.

Chart 1 shows the percentage of yearly output available for various orientation tilts (as per cent of maximum). These figures are typical for the UK - up to +/-10per cent difference can be expected depending on position in the country and type of PV cells used etc - it is recommended that a PV simulation is carried out using one of the PV simulation programmes available for an accurate estimation. Near horizontal 0° inclinations are not recommended as self-cleaning cannot be relied on up to about 10°.

It must be remembered that output varies with season. The shape of the daily insolation curves, and the monthly and seasonal trend in system performance is shown on the graphs 1 and 2.

Shading – Shade makes a big impact on the performance of a PV system. Even a small degree of shading on part of an array can have a very significant impact on the overall array output. Shade is one element of system performance that can be specifically addressed during system design – by careful selection of array location and layout and in the electrical design (string design to ensure shade effects only one string).

Module temperature – An increase in module temperature results in a decrease in performance (e.g. 0.5 per cent per 1°C above standard test conditions for a crystalline module). Sufficient ventilation must be provided

Orientation Chart showing yearly output for different orientation and tilt angles (%of maximum).

Tilt (°) from horizontial	Orientation - Compass bearing (°) measures from North													
	Horizontal	West			S.W.			South		S.E.				East
		270 °	255 °	240 °	225 °	210 °	195 °	180 °	165 °	150 °	135 °	120 °	105 °	90 °
	0 °	90	90	90	90	90	90	90	90	90	90	90	90	90
	10 °	89	91	92	94	95	95	96	95	95	94	93	91	90
	20 °	87	90	93	96	97	98	98	98	97	96	94	91	88
	30 °	86	89	93	96	98	99	100	100	98	96	94	90	86
	40 °	82	86	90	95	97	99	100	99	98	96	92	88	84
	50 °	78	84	88	92	95	96	97	97	96	93	89	85	80
	60 °	74	79	84	87	90	91	93	93	92	89	86	81	76
	70 °	69	74	78	82	85	86	87	87	86	84	80	76	70
	80 °	63	68	72	75	77	79	80	80	79	77	74	69	65
	90 °	56	60	64	67	69	71	71	71	71	69	65	62	58
	Vertical	Near horizontal 0 ° inclinations are not recommended as the self-cleaning cannot be relied on at less than about 10 °												

behind an array for cooling (typically a minimum 25mm vented air gap to the rear). For building integrated systems, this is usually addressed by the provision of a vented air space behind the modules. On a conventional pitched roof, batten cavity ventilation is typically achieved by the use of counter-battens over the roof membrane and by the installation of eaves and ridge ventilation.

Inverter ventilation – Inverters dissipate heat and should be provided with sufficient ventilation. Clearance distances as specified by the manufacturer (e.g. to a heatsink) should also be observed. Failure to follow this can cause a loss in system performance as the inverter will de-rate when it reaches its maximum operating temperature. This should be highlighted within the operation and maintenance manual and perhaps with a label – not to block ventilation – placed next to the inverter.

Building-integrated photovoltaic's (BIPV) are photovoltaic materials that are used to replace conventional building materials in parts of the building envelope such as the roof, skylights, or facades. They are increasingly being incorporated into the construction of new buildings as a principal or ancillary source of electrical power, although existing buildings may be retrofitted with similar technology. The advantage of integrated photovoltaics over more common non-integrated systems is that the initial cost can be offset by reducing the amount spent on building materials and labour that would normally be used to construct the part of the building that the BIPV modules replace. These advantages make BIPV one of the fastest growing segments of the photovoltaic industry.

The term **building-applied photovoltaics (BAPV)** is sometimes used to refer to photovoltaics that are a retrofit – integrated into the building after construction is complete. Most building-integrated installations are actually BAPV. Some manufacturers and builders differentiate new construction BIPV from BAPV.

Further reading

- wbdg.org
- NREL.gov
- U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy
- BRE.co.uk
- International Energy Agency, Paris, France
- mirriam-webster.com

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CPD SERIES **15** | MODULE **09** | MARCH **2018**

ENTRY FORM

PHOTOVOLTAICS

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

QUESTIONS

1. Which of the following ranges shows the typical per cent of total primary energy used by buildings in industrial countries?

☐ 10 per cent-20 per cent
☐ 30 per cent-40 per cent
☐ 20 per cent-30 per cent
☐ 40 per cent-50 per cent

2. Which of the following statements in NOT true?

☐ PV systems have been successfully used in thousands of applications.
☐ PV systems are a modular technology.
☐ PV modules are not technically well proven.
☐ PV modules can be suitable for mass global markets.

3. Which of the following statements are true from an architectural point of view? (Answers B and C)

PV requires extra land areas and can not be utilized in densely populated areas.
PV does not require any additional infrastructure installations.
PV can provide reduced planning costs.
PV may not reduce transmission and distribution losses.

4. Which of the following describes typical PV array commonly applied inverter ratios?

☐ 1:2
☐ 2:1
☐ 1:1
☐ 1:1.08

5. Which of the following factors does not affect PV performance?

☐ Orientation
☐ Pitch of blades
☐ Geographical location
☐ Height of building

6. What is the expected average electricity generation from a south facing inclined plane, unshaded PV array in the UK?

☐ 1,000 kWh per kW installed
☐ 500 kWh per kW installed
☐ 750 kWh per kW installed
☐ 250 kWh per kW installed

7. What is the typical resultant in decrease in performance per 1°C rise in temperature above ideal conditions for a PV crystalline module?

☐ 1.0 per cent
☐ 0.5 per cent
☐ 3.0 per cent
☐ 5.0 per cent

8. Which of the figures below indicate the expected number of inverter replacements for a 25-year life span PV array?

☐ 2 ☐ 3 ☐ 1 ☐ 4

9. Advanced 'smart inverters' with two-way communications can provide which of the following benefits?

☐ Reduces costs
☐ Ensure grid stability
☐ Reduce risk of power outages
☐ Increase inverter life span

10. Which year was the 'PV effect' discovered in Bell Telephone Laboratories?

☐ 1964
☐ 1954
☐ 1975
☐ 1963

Please complete your details below in block capitals

Name .... (Mr. Mrs, Ms) ....

Business ....

Business Address ....

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This is the eighth module in the fifteenth series and focuses on **photovoltaics**. It is accompanied by a set of multiple-choice questions.

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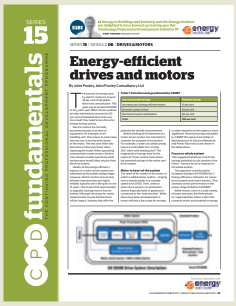

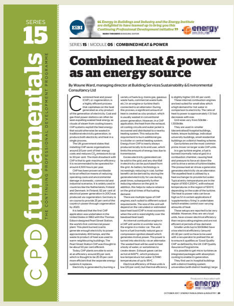

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