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MARK THROWER MANAGING EDITOR

MODULE THREE

PHOTOVOLTAICS

Let the sun shine down

Jamie Goth, managing director, Goth Energy Management Ltd

Photovoltaic (PV) arrays convert radiation from the sun into electricity. The technology has been in use in the UK for decades, but there has been a significant rise in its application since the introduction of the feed in tariff (FIT) in 2010.

PV arrays generate electricity only when there is sufficient sunlight. They produce their highest outputs when sunlight is at its maximum, their least when light levels are sufficient to trigger generation, and none at night. Sunlight is made up of photons that, when incident upon a PV array, excite electrons within its semiconductor material, freeing them to flow in conductive materials, generating electricity through what is known as the photovoltaic effect.

PV arrays are made up of PV cells that typically comprise silicon crystals doped with phosphorous or boron to increase the movement of free electrons and subsequent power generation. Polycrystalline and monocrystalline are the most common types of PV cell, accounting for over 90 per cent of sales globally. They achieve efficiencies of approximately 15 per cent and 17 per cent respectively, where efficiency is defined as the electrical energy output divided by the solar energy incident upon the active surface of the PV array.

Polycrystalline cells are typically cheaper than monoscrystalline cells, but are less efficient. Amorphous silicon PV cells have lower costs and lower efficiencies of 8 per cent. However, their use is primarily confined to calculators and other mobile devices rather than the widespread application to buildings seen for crystalline PV cells.

The power generated by a PV cell can be increased by using a concentrator system which acts to concentrate more sunlight onto its surface – typically through the use of lenses. Whilst this approach has begun to become cost effective in some applications, it is not in significant use for electricity generation in UK buildings.

Loss through inverter

PV arrays generate direct current (DC) electricity that must be converted to alternating current (AC) before grid connection. Conversion from DC to AC is achieved by an inverter. All inverters use a small proportion of the electricity generated to operate, amounting to a parasitic loss of the order of 5 per cent.

The proportion of losses can be greater at low PV array output, reducing as full capacity is approached. A range of inverter types, sizes, software and control systems are available on the UK market. They are selected for characteristics that suit the PV array they are to be connected to.

Parameters such as the minimum and maximum input voltage and power output ranges they are designed to operate over are taken into account to optimise system efficiency and reliability. A software technique known as maximum power point tracking (MPPT) is applied by inverter systems to minimise their internal losses and optimise PV system efficiency.

The power generated by PV arrays varies throughout the day according to light levels, intermittent shading and other factors. Power demand in buildings also varies in line with occupancy patterns and activity levels. There are few applications where these two are

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aligned. Consequently, if a PV array is sized to meet a building's peak demand, a significant proportion of the electricity it generates at times of non-peak demand is likely to be exported from the building to the national grid.

The proportion that is used in the building will depend upon the patterns of electricity demand. A building's load factor is the ratio of average to peak electricity demand. A high load factor signifies an average demand that is near to the peak demand – i.e. a relatively consistent electricity demand. A building with a high electricity load factor would consume a higher proportion of electricity generated by a PV array designed to meet its peak demand than a building with a low load factor.

However, in both cases, a greater proportion of the electricity generated would be used on site if the PV array were designed to meet the minimum, or base load daytime electricity demand.

TILT degrees	West								South										East
											-	-	-	-	-	-	-	-	-
	90	80	70	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80	90
0	87	88	90	91	92	92	93	93	93	93	93	93	92	92	91	90	89	87	86
10	84	87	90	92	94	95	95	96	96	97	97	96	95	94	93	91	89	87	84
20	82	85	90	93	94	96	97	98	99	99	98	97	96	95	93	91	88	84	81
30	78	83	87	91	93	96	97	98	99	100	98	97	96	95	93	89	85	81	78
40	75	79	84	87	92	94	95	96	96	96	96	95	94	92	90	86	82	77	72
50	70	74	79	83	87	90	91	93	94	94	94	93	91	88	83	80	76	73	70
60	65	69	73	77	80	83	86	87	87	87	88	87	85	82	78	74	71	67	63
70	59	63	66	70	72	75	78	79	79	79	79	79	78	75	72	68	64	61	56
80	50	56	60	64	66	68	69	70	71	72	72	71	70	67	66	60	57	54	50
90	41	49	54	58	59	60	61	61	63	65	65	63	62	59	60	52	50	47	44

First, energy efficiency

It is good practice to place higher priority upon the reduction of electricity demand than the generation of electricity from renewable sources. To this end energy conservation measures can be used to improve a building's energy efficiency prior to installing a PV array.

This will reduce energy waste and reduce the capacity of the PV array needed to meet a building's electricity requirements. Under UK government financial incentive schemes, the payment per kWh of electricity generated by a PV array is lower for buildings that fail to meet a minimum standard of building energy performance, a D rating energy performance certificate (EPC), than for those that meet it.

Once a building's electricity demand has been reduced, grid-connected PV arrays are sized to take account of a number of factors, including residual peak and minimum power demands; the area available to accommodate a PV array; the building owner's appetite for financial risk; occupancy patterns and the value of feed in tariff (FIT) available. In the domestic market, it is common for installers to recommend the maximum capacity of PV array that can be safely installed on the roof of a house, up to a maximum of 4kWp, at which capacity the value of the FIT reduces. This capacity of array is typically sufficient to meet the average UK household's annual electricity needs. However, how much is consumed as it is generated will vary considerably between households and a grid connection will remain essential to ensure all instantaneous demands can be met. Hence the PV array could be considered to be meeting the majority of the householder' electricity consumption and offsetting the rest.

The location of a PV array affects its ability to generate electricity and potentially its useful economic life. The ideal location is an unshaded position in a south-facing orientation at an inclination from the horizontal of about 30 per cent. The ideal climate should be sunny and not exposed to extremes of temperature, wind and rain. A good electrical infrastructure and balanced electricity distribution grid are also requirements.

Impact of shading

Shading by trees, buildings, pylons, roof geometry and furniture can have a significant impact upon the power generated by a PV array. The excitement of electrons within the semiconductor material of a PV cell is significantly reduced by shading. However, where one shaded cell is in a circuit with unshaded cells, the flow of electricity from the whole circuit can be reduced, further reducing the power generated by the array. Even fairly modest shading can therefore have a significant effect upon power output.

Both the direction a PV array is facing and its angle of tilt relative to the sun are important factors in optimising electrical output. A south-facing orientation will be ideal through the majority of the day in the UK, whereas east and west orientations will only optimise direct sunlight in the morning and evening respectively. While the ideal inclination from the horizontal varies with latitude, time of day and season, the optimum for a fixed-axis system in many parts of the UK is 30˚.

The chart above is taken from the Energy Saving Trust's website[1] and shows how the percentage output of a PV array varies with orientation and inclination. It illustrates that output is optimised when facing due south at an inclination of 30˚, achieving a nominal 100 per cent of power output commensurate with its electrical efficiency and the level of insolation. Output drops off as either inclination or orientation move away from the idealised position.

Providing the orientation is between due west and due east and inclination is below 30˚, power output is mainly above 80 per cent of optimum. However, when the inclination rises above 70˚, output falls to below 80 per cent for all orientations and below two thirds for all orientations when vertical.

Despite the drop off in power output with increasing inclination, in the right orientation, building integrated PV (BIPV) arrays mounted on walls of selected buildings have been shown to be cost effective when they are used to displace high cost façade materials.

The impact of inclination upon power output is indicative only and varies with latitude. Furthermore, the optimum angle in summer is steeper than that in winter. A system in the north of Scotland will need to be set up differently from one in Cornwall. The level of insolation received in Scotland will be less, but, with UK government incentive schemes there is still a good financial case for the exploitation of PV throughout the UK. Where system design allows, it is possible to manually adjust the angle of inclination seasonally or twice yearly to optimise power output.

This can increase annual power output by the order of 5 per cent. Greater increases can be achieved by systems that continuously track the sun's position and optimise both inclination and orientation to meet this. However, the use of a fixed angle of inclination is the most common practice in the UK, primarily on the grounds of a better return on investment.

Introduction of FIT payment

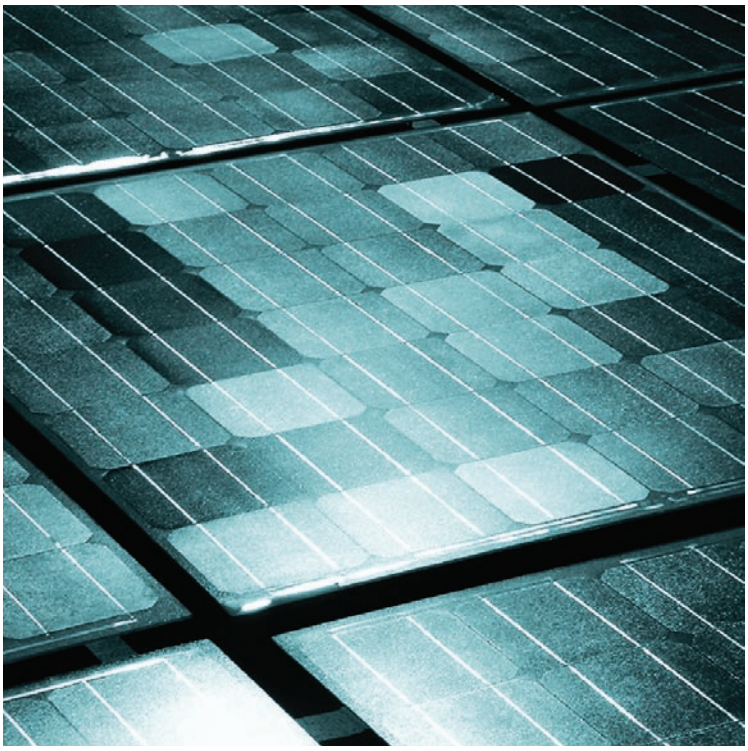
In 2010 the UK government introduced the FIT, a payment per kWh generated for a range of qualifying low and zero carbon (LZC) technologies, including PV arrays. FIT payments are made by the electricity supplier to the electricity account holder. Payments were originally worth 48.07 p/kWh for qualifying domestic and small commercial arrays of up to 4 kW.

Early adopters still receive this rate – index linked to the retail price index (RPI) for 25 years. The aim of the FIT was to increase the take up of LZC technologies and reduce the cost of manufacturing, distributing and installing them. This has been achieved, with the cost of PV arrays dropping to the order of a quarter of their price before the introduction of the FIT. Tariff rates have subsequently reduced, with the rate available for domestic scale arrays standing at 14.38 p/kWh. This payment will be made for all electricity generated, whether or not it is used in the building, or exported to the grid. The payment will be made for 20 years, index linked to RPI. The FIT will reduce for new PV installations as the number of installations increases in the future in accordance with a derogation procedure the Government introduced to control the cost of the incentive scheme.

In addition to the FIT, a payment of 4.64 p/kWh is made for electricity exported to the grid. The quantity of electricity exported is generally metered for larger installations, but only deemed for small ones. Deeming is intended to reduce costs where the cost of a meter and data collection associated with it would form a significant proportion of the value of the electricity exported.

In addition to the FIT, owners benefit from the avoided cost of electricity displaced by the PV array, which is typically in excess of 10 p/kWh for domestic and small commercial premises. Avoided costs of climate change levy (CCL) and the Carbon Reduction Commitment Energy Efficiency Scheme (CRC) raise avoided costs by a further 10 per cent.

According to the Energy Saving Trust, a 4 kWp PV array could generate 3,700kWh of electricity in a year, which is roughly equivalent to a typical UK household's electricity needs. This would create value and avoid costs for domestic electricity users amounting to an estimated £750 per annum. The installed cost of a system of this size would be of the order of £6-7.4k, enabling a payback period on the initial investment of less than 10 years to be achieved.



> **"According to the Energy Saving Trust, a 4 kWp PV array could generate 3,700kWh of electricity in a year, which is roughly equivalent to a typical UK household's electricity needs"**

An alternative to a grid-connected PV array is one installed along with battery or other energy storage systems. These systems are not eligible for the FIT, reducing the income generated by over £500 and increasing the capital cost by the addition of a battery. The combination of these two would extend the simple payback period to over 25 years. This would be longer than the warranty provided on PV arrays and approaching their useful economic life.

Educational interest

PV arrays provide qualitative benefits in addition to the supply of electricity. They reduce carbon emissions, assisting organisations to meet their carbon targets. Many local authorities that have installed PV arrays on the roofs of primary schools have found that they have been of educational interest to school pupils. They raise awareness of clean energy and other environmental issues, particularly as they are usually visible without being intrusive.

As with other LZC technologies, PV arrays can assist in securing both Planning Permission and compliance with Building Regulations for construction and refurbishment projects. They are simple to integrate into buildings and their services compared to the majority of other renewable energy technologies. This also makes them an attractive option for demonstration projects

The structural integrity and waterproofing of roofs should be checked prior to the design and installation of PV arrays. They can place significant stress upon a roof through their weight, further exacerbated by wind loading. This in turn can affect the waterproofing of flat roofs.

In areas where vandalism is a known problem it may be inadvisable to install PV arrays – particularly on buildings that are not occupied or supervised outside of office hours.

Reference

1) http://www.energysavingtrust.org.uk/var/ezflow_site/storage/images/media/generate-your-own-energy/images/solar-pv-tilt-effect/27882-2-eng-GB/Solar-PV-tilt-effect_mainstory1.jpg

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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

Q1. According to the Energy Saving Trust, what is the typical cost of a 4 kW PV array?

- ☐ £6-7,400
- ☐ £6-740
- ☐ £674

Q2. What is the name of the incentive scheme that provides an income for electricity generated by PV arrays?

- ☐ Green Deal
- ☐ Feed in Tariff
- ☐ Renewable Heat Incentive

Q3. How do incentive scheme payments for existing PV arrays change with time?

- ☐ They don't change, they are set at a fixed cost
- ☐ They rise by a fixed amount each year
- ☐ They rise with the retail price index (RPI)

Q4. Which of the following is a potential qualitative benefit of PV arrays?

- ☐ Compliance with Building Regulations
- ☐ Reduced heating costs
- ☐ Improve street lighting and signage

Q5. Which orientation optimises output of a PV array?

- ☐ North
- ☐ South
- ☐ East

Q6. Which tilt angle is nearest optimum for a fixed position of a PV array?

- ☐ 0˚
- ☐ 30˚
- ☐ 70˚

Q7. When was the Feed in Tariff introduced in the UK?

- ☐ 2000
- ☐ 2005
- ☐ 2010

Q8. What is the typical efficiency of a polycrystalline PV cell?

- ☐ 10 per cent
- ☐ 12 per cent
- ☐ 15 per cent

Q9. How does the efficiency of a monocrystalline PV cell compare to this?

- ☐ Equal efficiency
- ☐ Higher efficiency
- ☐ Lower efficiency

Q10. What PV capacity would generate sufficient electricity for a typical domestic property?

- ☐ 2 kW
- ☐ 3 kW
- ☐ 4 kW

Please complete your details below in block capitals

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

Business ....

Business Address ....

....

....

....

Post Code ....

email address ....

Tel No. ....

Completed answers should be mailed to:

The Education Department, Energy in Buildings & Industry, P.O. Box 825, GUILDFORD, GU4 8WQ

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