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The Application of Solar Photovoltaic (PV) Generation Technology to Data Centre Facilities

Dr Ian F Bitterlin

PhD BSc(Hons) BA DipDesInn MCIBSE MIET MBCS MBIFM MIEEE



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Head office: Hartham Park, Corsham, Wiltshire, SN13 0RP

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Background

As electrical power costs climb and corporate entities wish to advertise their 'green' credentials the application of sustainable power generation to data centre facilities has gathered pace. Although the application of on-site generation using renewable technologies is usually limited by available land, rooftop space or fuel logistics an option that increasingly attracts attention, and publicity headlines, is that of solar photovoltaic panels.

This extended and revised paper (version 5.1 supersedes version 5 previously published in August 2010) attempts to clarify the practicalities of applying local photo-voltaic power generation to a typical data centre.

Technology

Current technology is based upon encapsulated wafers of silicon PV cells that convert solar radiation to a low voltage DC. The voltage output is proportional to the strength of the radiation falling onto the cell. The cells are generally built into 12V or 24V panels and those panels can be daisy-chained to a relatively high DC voltage suitable for inverter conversion to AC (for example to 230V) or applied to a low voltage DC load to avoid conversion losses. At low voltage the distribution distance has to be relatively short to minimise I^2R losses and volt-drop and avoid large cross-section copper conductors.

To produce maximum power the panels must be tilted to face the 'brightest' part of the sky. In the UK this means tilted 40° from the horizontal and facing due south. The cells should not be overshadowed by structures, buildings or vegetation for the entire daily cycle of the sun across the sky in every season. Contrary to common perception the cells need daylight not sunshine – but the clearer the sky the higher the level of radiation that reaches the silicon-cell face.

It is not uncommon to see solar-PV panel built into the vertical walls of buildings, some even not south facing, although this limits the effectiveness of energy collection. If the wall is equator-facing then at high latitudes we shall see that wall-mounting (vertical) can be preferential to roof-mounting (tilted).

Intermittence

The obvious limitation of solar PV is the daylight (strictly speaking, ‘radiation’) hours per day and intensity that the PV panels are exposed to - the ‘intermittence’ of the output being in common with other renewable energies such as wind, tidal, wave etc.

The intermittence raises the first design issue – energy storage. With data centre loads being virtually constant the choice is between a dedicated (separate) load and an energy storage system to bridge the dark hours (e.g. lead-acid batteries) or to parallel the output of the PV system with the mains supply and simply use the power collected to reduce the demand on the grid. In the first case you have to accept the charge/discharge losses of the battery system and in the second case the losses in the voltage boost converter and DC/AC inverter. Clearly in both cases the fuel is ‘free’ so classic ‘efficiency’ issues should not apply – but the capital cost of plant and a Return on Investment (RoI) is a factor in the choice.

Insolation

At the latitude of the UK the peak solar radiation is around 1kW/m² and, as we shall see, the daily/seasonal cycle will aggregate to a gross value of around 1,135kWh/m²/year given optimised installation and alignment conditions.

It is interesting to bracket the limits of effectiveness of PV in a European context so we shall consider three latitudes:

- 70°, which is the far northern tip of Europe, Finland
- 50°, covering Southern UK (London), Netherlands, Denmark etc
- 30°, which represents the far southern limits of Europe; the south Mediterranean coastal countries, Morocco (Agadir), Algeria, Libya, Egypt etc

All the data comes from the Atmospheric Science Data Center of NASA – Surface Meteorology and Solar Energy at <http://eosweb.larc.nasa.gov> accessed 25th November 2010.

In Table 1 we can see the daily average solar radiation incidence by month for a horizontal surface. The relationship between latitude and incident radiation is clear.

Monthly averaged insolation incident on a horizontal surface (kWh/m²/day)

Latitude	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
70°	Northernmost point Europe	0.00	0.19	1.10	2.56	3.94	4.55	4.01	2.92	1.56	0.38	0.01	0.00	1.77
50°	London	0.82	1.46	2.45	3.72	4.71	4.97	4.98	4.34	2.93	1.79	0.99	0.62	2.82
30°	North African Mediterranean	3.38	4.57	5.93	7.26	7.58	7.82	7.74	7.26	6.30	4.59	3.65	2.99	5.76

Table 1

In Table 2 the same format data is shown for a vertical surface. It is clear that the lower the latitude the less effective is a vertical application.

Monthly averaged radiation incident on an equator-pointed vertical surface (kWh/m²/day)

Latitude	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
70°	Northernmost point Europe	0.00	0.00	1.54	2.42	2.91	3.06	2.76	2.54	1.99	0.00	0.00	0.00	1.44
50°	London	1.29	1.90	2.30	2.67	2.76	2.68	2.78	2.86	2.53	2.14	1.51	1.04	2.21
30°	North African Mediterranean	4.19	4.73	4.24	3.18	2.33	2.03	2.14	2.74	3.76	4.13	4.24	3.91	3.47

Table 2

It is clear that the energy collection opportunities are dependent upon the inclination of the receiving surface but the investment in a 'solar tracking' installation cannot normally be justified. Table 3 shows the 'average optimum' tilt angle and the overall results obtained. In every case the energy incidence is higher.

Monthly averaged radiation incident on an equator-pointed tilted surface (kWh/m²/day)

Latitude	Averaged Optimum Tilt Angle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
70°	50° from the horizontal	0.00	0.00	1.69	2.98	3.80	4.18	3.74	3.18	2.26	0.00	0.00	0.00	1.82
50°	40° from the horizontal	1.27	2.06	2.93	3.99	4.66	4.74	4.83	4.52	3.39	2.41	1.51	1.00	3.11
30°	30° from the horizontal	4.66	5.93	6.75	7.22	6.86	6.77	6.83	6.94	6.79	5.61	4.89	4.22	6.12

Table 3

In round terms we can see that the Southern Mediterranean incident radiation is 'twice' that of London and 'three times' that of the northern tip of Finland.

Now we have the radiation energy data we can consider the conversion efficiency to electrical power.

Energy conversion efficiency

The average conversion efficiency using the current silicon based technology has been in the order of 15% with a peak of up to 20%. Only a radical change in the material technology will enable future conversion efficiencies higher than 20-25%.

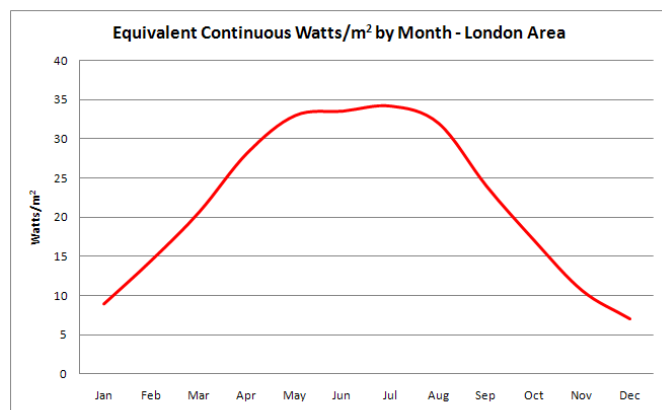
In Table 4 we have taken only 50° latitude (e.g. London) and assumed a conversion efficiency of incident radiation to electric power output of 17%. By month we have converted the data in Table 3 to show the 'equivalent continuous' Watts/m². The 'peak' output will be in the order of 3x the 'continuous' but the figure shown represents a more useful number for comparison to possible data centre loads.

Monthly power generation for an equator-pointed 40° tilted PV panel in London (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Days per month	31.0	28.0	31.0	30.0	31.0	30.0	31.0	31.0	30.0	31.0	30.0	31.0	365 days
kWh/month/m ² incident radiation	39.4	57.7	90.8	119.7	144.5	142.2	149.7	140.1	101.7	74.7	45.3	31.0	1137 kWh/m ²
Conversion Efficiency	17%												
kWh/month/m ² power output	6.7	9.8	15.4	20.3	24.6	24.2	25.5	23.8	17.3	12.7	7.7	5.3	193 kWh/m ²
Hours per month	744	672	744	720	744	720	744	744	720	744	720	744	8760 hours
Equivalent continuous Watts/m ²	9	15	21	28	33	34	34	32	24	17	11	7	22 W/m ² Ave

Table 4

Graph 1 shows the continuous equivalent power output per m² of PV panel and the typical seasonal effects of southern UK climate.



Graph 1: PV Panel Power Output - 40° tilted panel, facing South

Physical deployment and space availability

The ideal southern UK location is on a flat roof of the data centre, assuming that the heat rejection plant is not already occupying the space, tilted to 40° and facing south.

If the building is orientated such that a large wall is facing south and is not over-shadowed by other buildings or trees then a vertical application may perform just as well.

We can relate the space available on the roof to the space taken up by a single IT cabinet – which is around 5m² of gross floor area when combining raised floor & plant-room space.

Diagram 1: Horizontal space requirements

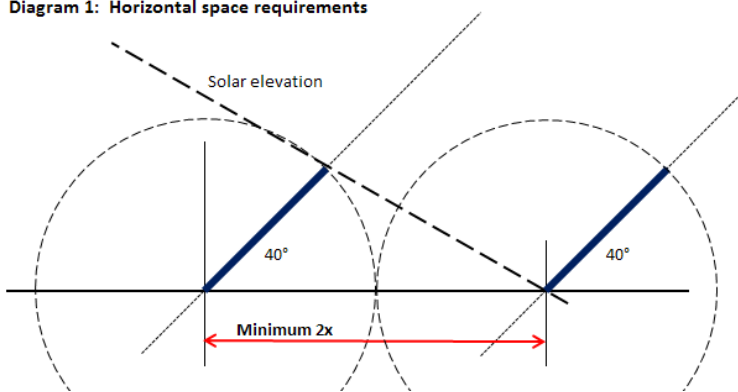


Diagram 1 illustrates the maximum density of PV panel to allow for shading and access. So, to allow for service access and the panel-tilt the maximum solar cell surface area in a 5m² roof footprint will be around 2.5m². This is for a single storey facility – with proportionately less for multi-storey facilities.

On-site power generation

It is simple arithmetic to calculate the kWh/year produced by a 2.5m², 17% efficient, PV array with a gross insolation of 1,135kWh/m²/year. The result is 482kWh – equivalent to a constant load of just above 55W.

Generation capacity Vs demand

The single IT cabinet consumes 5m² of roof space onto which we can fit 2.5m² of PV array which generates 1,135kWh/year. Without considering high-density facilities and ignoring the cooling load altogether, the constant electrical load of the average IT cabinet is in the order of 4kW (a modest power density of around 1500W/m²) which is equivalent to 35,000kWh/year.

It can be seen that a PV array of current silicon technology will produce around 3.25% of a modest IT load even if the entire roof space of a single storey facility is covered. A vertical application may reduce this to 2.5 - 3%.

Another way of considering the power generated is to compare it with a Blade-Server chassis, typically occupying only 7U of a single 42U high IT cabinet, whose average demand is 5.5kW. The PV array will contribute less than 3% of a load occupying 1/6th of a cabinet.

If a separate load is planned for the PV installation then a 100% rooftop coverage array could be relied upon to generate sufficient power for high efficiency motion-detected aisle lighting in the raised floor space (requiring about 50W per cabinet predominately during the hours of daylight) and the security-access/BMS/EMS systems.

Embedded Carbon & RoI

It is worthy of note that the embedded carbon (from the energy used in manufacture) in the silicon based cells is not recovered through power generated in service for at least four years. It is anticipated that new technology using more exotic materials will improve both the conversion efficiency and reduce the embedded carbon.

Without government subsidy for the kWh produced (via demand side reduction) the capital cost of PV currently prohibits any financial Return on Investment since, generally, the cost of electricity would have to double and the capital cost of the cells halve before a sub-10 year RoI will be possible.

Conclusions

The high and continuous load found in data centre facilities is not conducive with the low power and intermittence of solar photo-voltaic on-site power generation.

Demonstration projects, especially those aided by government subsidies for installation and generation, are possible and could reduce the typical load by 2-3% if the entire roof space of a single storey facility is utilised. A Return on Investment is not currently available and CO₂ emission savings are marginal in the service period beyond 4-5 years after installation. However, all, if any, emission savings depend upon the power-generation fuel mix in the country of installation or any special national contracts in place to purchase 'green' power from sustainable sources.

For IT power densities of c10kW/cabinet the proportion of sustainable PV derived energy falls to less than 0.6% when the cooling system energy (at a PUE=1.5) is taken into account.

End

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