Performance Of West Oxfordshire District Council Office's Photovoltaic Arrays

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Introduction and site specification

The West Oxfordshire District Council office building in Witney contains 23 kWp of building integrated photovoltaic arrays across 6 different roofs, each with different pitches and orientations. Two roofs face NNE and WNW, and so do not receive direct sunshine throughout the course of the year. The building is seen as an important test of the effects of non-optimal orientations as part of the Field Trial process, although it is acknowledged that electricity yields will never reach optimal levels.

The building integrates the majority of the PV as a-Si solar shingles, with 2 kWp of c-Si cells as glass-glass laminates. The majority of the PV is located on Roof 1, with roughly equal amounts on roofs 2-5, and is made from Unisolar amorphous silicon roof shingles. Roof 6 is the glass laminates. Each of the 16 strings is connected to an SMA inverter; either a 1700e or 1100e depending on the string size. Full details are shown in Table 1.

Seven insolation sensors were mounted on poles above roof height - one horizontal and six in the plane of each roof. Temperature sensors noted the temperature of the arrays, and import and export to and from the building were recorded. All data were recorded at 5 minutely intervals for a monitoring period of 2 years by Sunny Boy Control dataloggers.

System Reliability

There are three major monitoring problems that have resulted in either loss of data or non-optimal performance of the system

Human or monitoring hardware errors.

Because the system is not automated human error resulted in small periods of loss of data. Such losses are almost inevitable, and even an automated system would require constant checking to ensure reliability. Hardware failures (*e.g.* computer server failures, back-up failures) has also resulted in some more lengthy losses of data including no data from November 2004.

Tripped protection circuit.

Protection circuit switches tripped off,

Roof no.	Orientation	Inclination	Technology	No. units	Peak Power kWp	configuration	String Peak Power (kWp)	Inverter Size (kWp)
1	ESE	30°	Shingles	460	7.82	4 strings of 23 shingles	1.564	1.7
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2	SSW	40°	Shingles	240	4.08	3 strings of 30 shingles	1.53	1.7
						3 strings of 30 shingles	1.53	1.7
						2 strings of 30 shingles	1.02	1.1
3	ESE	40°	Shingles	180	3.06	3 strings of 30 shingles	1.53	1.7
						3 strings of 30 shingles	1.53	1.7
4	NNE	40°	Shingles	135	2.30	3 strings of 27 shingles	1.38	1.7
						2 strings of 27 shingles	0.92	1.1
5	WNW	40°	Shingles	224	3.81	3 strings of 28 shingles	1.43	1.7
						3 strings of 28 shingles	1.43	1.7
						2 strings of 28 shingles	0.95	1.1
6	SSW	5°	Glass Laminates	16	2.08	1 string of 16 laminates	2.08	1.7
			TOTAL SHINGLES	**1239**	**21.06**			
			TOTAL PV	**1255**	**23.14**			

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Table 1. Specification of the West Oxfordshire District Council Offices Array

thereby isolating the inverter and halting electricity production. This is not a fault with the inverter, but rather caused by voltage fluctuations on the grid side of the array Once tripped, the inverter will not turn on until the switch is manually reset. This requires that the problem is noticed swiftly and someone on site can correct the fault.

For the duration of the monitoring study, this process has been well streamlined, but 116 inverter-days of electricity generation were lost from 12 instances of tripped circuit protection. Now that the monitoring contract has expired, it is important that the management of the array is equally rigorous. It would be entirely conceivable for a problem to go unnoticed for many months without the sufficient expertise to spot problems, and a regular procedure for assessing the performance of the system.

Failed inverters.

There were long periods of zero electricity production due to failed inverters. Of the 18 inverters on site, 2 had failed within the first year of operation, and resulted in 164 inverter-days of downtime. Again, such problems were only spotted due to the presence of a thorough monitoring set-up. The two inverters were replaced by the system installers within 3 month's of notification. These periods of inverter failure have noticeably affected yields on roof 2 (see Figure 1).

Energy Production

Overall

The WODC array produced a total of 24,521 kWh of electricity over the 2 year monitoring period (Nov 03-Oct 05), an average of 12,260 per annum. After the inverters, a total of 10,840 kWh of AC electricity was produced for use within the building.

The specific yields of the system were low, being 529 kWh/kWp DC and 469 kWh/kWp AC, although there is a variation between the roofs (See Table 2). However, none of the arrays are optimally oriented, so yields from this system were expected to be lower than the typical UK values of 750-800 kWh/kWp [1]. Normalising by insolation received, the performance ratios are also low, averaging 48% compared to 70-80% for a well-performing system. Reasons for the underperformance are explained in more detail below.

	DC Yield (kWh/kW_p)	AC Yield (kWh/kW_p)	Performance ratio (%)
Roof1	670	598	59
Roof 2	490	436	41
Roof 3	655	583	55
Roof 4	389	335	42
Roof 5	397	340	45
Roof 6	288	248	22

Table 2. Annual Specific Yields of roofs 1-6

As expected the roofs with a southerly aspect outperform those with a northerly aspect. Roof 2 gave a lower yield than expected due to the inverter failures in summer 2004 and 2005 (see Figure 1). Roofs 4 and 5, which both face northwards gave respectable yields of 400 kWh/kWp but due to inverter sizing were inactive for much of the year. Roof 6 yielded just 300 kWh/kWp but is heavily shaded.

Seasonal Energy Production

Figure 1 shows the seasonal variation in production throughout the course of the monitoring period.

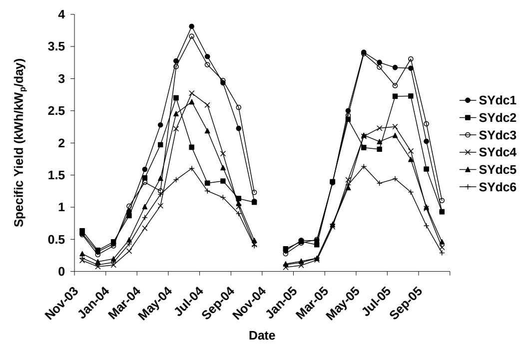

Figure 1. Average Daily specific yields through the year.

Roofs 1 and 3 reach an average daily production in the summer months of 4 kWh/kWp per day. On an individual clear bright day, these roofs are capable of generating up to 10 kWh/kWp per day. Roof 2, should follow a similar output profile, but the inverter failures have severely limited electricity output. The northerly facing roofs also perform impressively well in summer, averaging 3 kWh/kWp per day despite not receiving direct sunshine. This is an indication of the brightness of diffuse light, coupled with longer daylight hours, in the summer months. However, output in the winter months is very low, and hampered by the way the system is sized (see below). Roof 6 performs comparably to other roofs in the winter months, but poorly in summer.

Roof 6 is shaded by the building and a tree during the morning and early afternoon, which dramatically reduces output (see Figure 2) by reducing the direct sunshine component received by the roof.

Daily profiles

Because of the different orientations of the roofs it is interesting to examine this influence on the daily generation profiles.

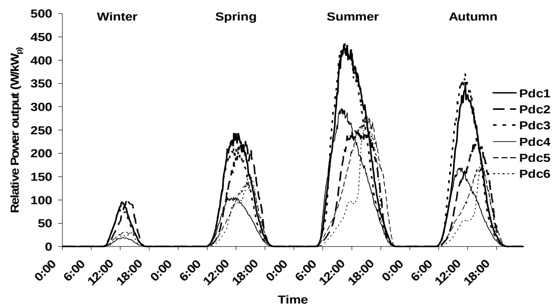

Figure 2. Daily profiles of the six roofs.

As expected, the roofs with a westerly aspect (2 &5) reach a maximum in the afternoon, whilst those with an easterly aspect (1, 3 & 4) peak in the morning. Roof 6 also peaks in the afternoon despite being virtually horizontal, due to the extensive shading from the building during the morning. The impressive summer performance of northerly facing roofs 4 and 5 is again apparent.

Specific Performance Issues

Oversizing of inverters

The size of the strings and inverters are shown in Table 1. It should be noted that all inverters are oversized for their arrays, and those with 1.1 kW inverters have all shown severe performance problems. Oversizing of inverters is a debatable practice in maritime climates where inverters should be marginally undersized for optimum performance as very high insolations are not observed[2]. The DTI Installation guidelines[1] suggest that inverters should be between 0.8 and 1 times the size of the string. This is especially true at the Witney site where none of the roofs have an optimal orientation and so do not receive maximum insolation. Roofs 4 and 5 do not receive insolation of more than 800 Wm^{-2}, meaning the inverter is oversized by approximately 50%.

The oversizing of the inverters has two different effects on performance:

First, the inverters spend more time operating in their low efficiency range at low power inputs, meaning that electricity generated by the PV array is not converted to useable AC electricity.

Second, inverters require a certain amount of input power to turn on. If the inverters are oversized higher insolations are required to achieve this. Therefore, the operational time of each array is reduced. One string on roof 4 did not turn on at all in December 2005. Combining these two effects results extremely low inverter efficiencies (Figure 3) in the winter months in those roofs with a northerly aspect - roof 4 averages just 33% in December 2004.

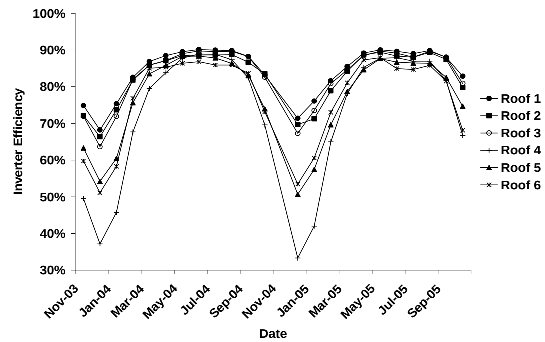

Figure 3. Seasonal Variation of Inverter Efficiencies.

It could be argued that this is not so important as energy yields in winter are low anyway. However, energy is delivered roughly constantly across all insolations in the UK[3], so performance at low insolations is a vital aspect of PV array performance in the UK.

Capture and system losses

The array capture losses (see Figure 4) from the strings are a significant factor in the low performance ratios observed at the Witney site.

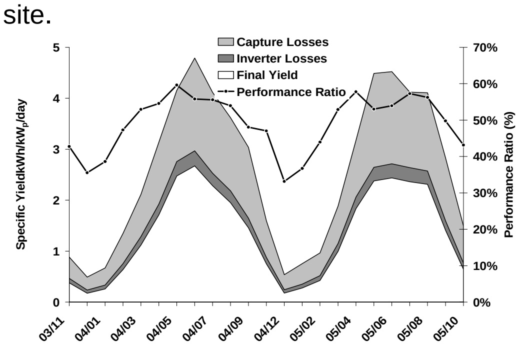

Figure 4. Capture and system losses, and performace ratio throughout the year

There are several possible reasons for this including shading, inverter malfunction, the inverter oversizing, inverter tracking and the PV roofing product itself. These are discussed in more detail below.

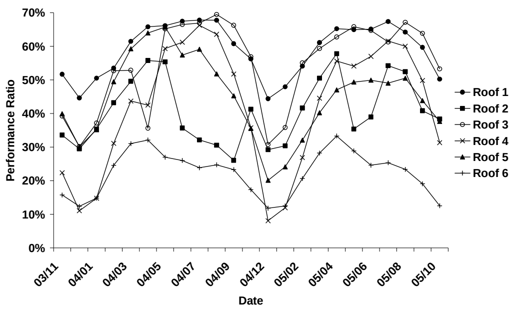

Figure 5. Average Perfomance Ratios for each of the roofs.

Shading

Shading is observed on roofs 1 and 6. Although the whole of roof 1 is not shaded by the adjacent building, the most heavily shaded string produces just 40% of the electricity of the least shaded. Roof 6 also shows shading from the building in the morning and early afternoon (see Figure 2) making Roof 6 the poorest performing roof.

Module Mismatch

Previous research[3] has suggested that the Unisolar product is not uniformly manufactured, and that the poorest modules in a string can limit the performance. With long strings of up to 30 shingles, the chances of module mismatch are higher high. Alternatively, it is possible that modules were damaged during installation, which could have a similar effect of reducing yield. Further investigation would necessitate the individual testing of every strip of shingles - which is beyond the scope of this project.

Inverter Tracking

Poor inverter tracking has been observed and can be detected by a surge in voltage and dramatic drop in current, or vice versa - in each case the power will drop off dramatically from the desired maximum power point. The power output profile will also no longer be the same shape as the insolation profile. Voltage spikes due to poor inverter tracking are clearly visible in Figure 6. However, even during periods of good operation, there is clearly some movement around the maximum power

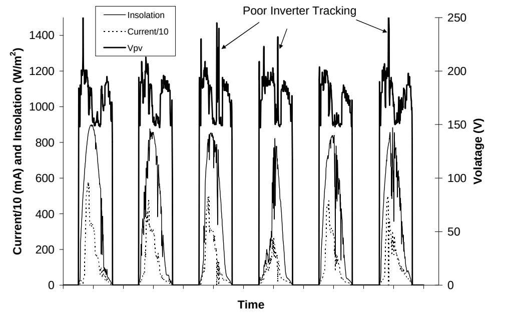

Figure 6. Inverter tracking on string 1_1 between 01/09/04 and 06/09/04.

point, with a spiky voltage profile. The current is also no longer proportional to the insolation. The SMA inverters have a history of poor tracking of amorphous silicon arrays[4] and this may be the case here. However, it is not possible for the present monitoring set-up to determine this as the inverter is both maximum power point tracker and measurer of current and voltage values.

Conclusions

The array at West Oxfordshire District Council has provided a useful comparison of arrays at different orientations, and has shown that summertime performance of arrays of northerly aspect are surprisingly good. However, the system has been hampered by technical failures, and design flaws that have limited electricity output and lead to low performance ratios. This is likely to be a a combination of poor inverter tracking, shading, mismatched or damaged modules, and oversizing of inverters.

References

[1] DTI, “Photovoltaics in Buildings: Guide to the installation of PV systems”, 2nd Edition, ETSU S/P2/00355/REP/1, 2006

[2] S. Islam, A. Woyte, R. Belmans, J. Nijs, "Undersizing Inverters for Grid Connection - What is the Optimum?", PV in Europe, Rome, 2003.

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[4] G.J. Conibeer, D. Wren, Proceedings 16th European Conference on Photovoltaic Solar Energy Conversion, Glasgow (2000).