A Summary of Outdoor Testing and Modelling of PV Systems

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ABSTRACT

BP Solar have conducted long term outdoor tests on modules and arrays worldwide (see figure 1) of different technologies. This poster summarises some findings since 1998.

Figure 1: More than 100 sites have been studied worldwide

COMPARISON OF DIFFERENT PV TECHNOLOGIES VS OUTDOOR PARAMETERS MEASUREMENTS

A useful 3D graphic has been developed to study module and array performance (see figures 2 to 5). The following is a description of the data in the figures:

a) Axes

Front: Module temperature left (-20C cold) to right (+80C hot)
Right: Irradiance varies front (0 kW/m² dull) to back (1.2 kW/m² bright)
Vertical: Measured performance parameter such as current, voltage, efficiency or power is shown on the vertical axis

b) Measurements vs Tmodule and Irradiance

A mesh of averaged values per 10C and 0.1kW/m² bin is shown in black.

c) Projections of points on the walls

Bottom: black (Tmodule vs irradiance)
Left wall: green (performance vs irradiance)
Back wall: orange (performance vs Tmodule).
(Cubic average fits to the data can also be shown).

d) Histograms on left and back walls

Distributions of the insolation energy kWh/m² vs bin
Left wall: energy/insolation bin
Back wall: energy/Tmodule bin.

Figures 2-5 show 4000 points representing a year of 10 minute averages for different modules at ISET, Kassel Germany.

Figure 2 is a BP 7180 module, the efficiency measured under real world conditions is high and almost flat with irradiance, falling slightly under the highest module temperatures (although as the histogram on the back wall shows there is little irradiant energy with module temperatures above 50C). The z axis shows the nominal efficiency of 14.3%.

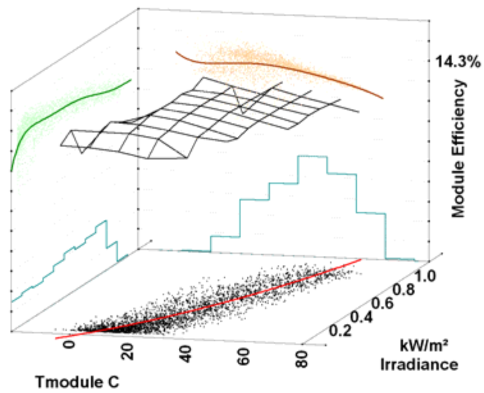

Figure 2: BP 7180 Efficiency vs module temperature and Irradiance.

Figure 3 gives the equivalent for a BP 3160 module; a similar shape to the normalised efficiency is obtained. The z axis shows the nominal efficiency of 12.7%.

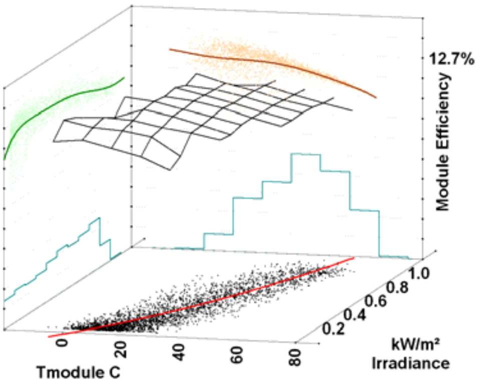

Figure 3: BP 3160 Efficiency vs module temperature and Irradiance.

Figure 4 is the equivalent for a competitor's CIS module, overall the measured/nominal efficiency is lower than the BP 7180 or the BP3160 (even though the nominal efficiency is only 9.1%) and there is no improvement at low light level performance.

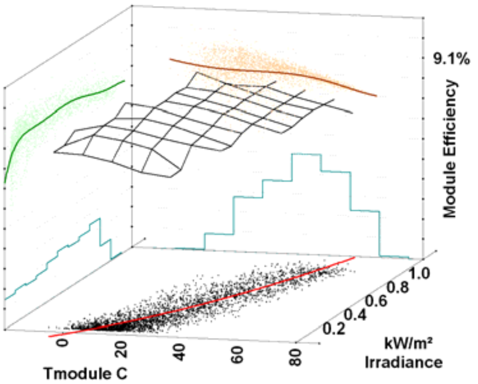

Figure 4: Competitor CIS Efficiency vs module temperature and Irradiance.

Figure 5 illustrates the data for another competitor's a-Si module, the measured/nominal efficiency is much lower than the other modules (it has either degraded below the 6.3% claimed or was supplied under nominal power) and there is almost no improvement at low light level despite claims in the literature. There is a slight improvement at higher temperatures, partly due to the better gamma (=1/Pmax x dPmax/dT) factor but in general the efficiency of this module is only about 0.8 of the nominal 6.3%.

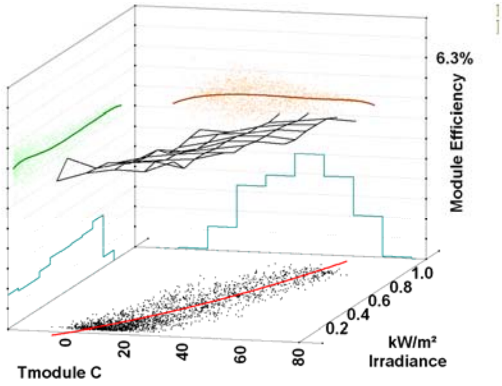

Figure 5: Competitor 3J a-Si Efficiency

Figures 2 to 5 showed the efficiency versus Irradiance and Module Temperature which are the two most important effects in determining the module performance.

Other parameters such as Diffuse or Beam (Direct) Fraction, Angle of Incidence and Solar height have also been studied.

Figures 6-8 show the module efficiency of a BP 7180 measured at ISET for 1 year from July 04 to July 05. The dark blue dots show more than 23000 10 minute averaged measurement points [1].

The light lines give a cubic best fit for efficiency; the yellow histograms show the amount of insolation energy in each bin on the horizontal axis to an arbitrary y-axis.

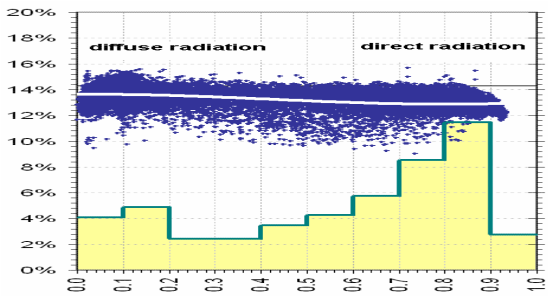

Figure 6) Module efficiency vs Beam Fraction (diffuse to the left, direct to the right)

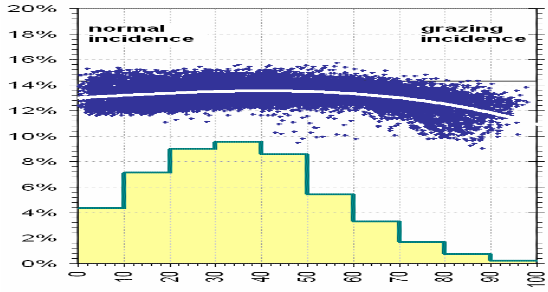

Figure 7) Module efficiency vs Angle of Incidence (°) Normal incidence to the left, grazing angle to the right

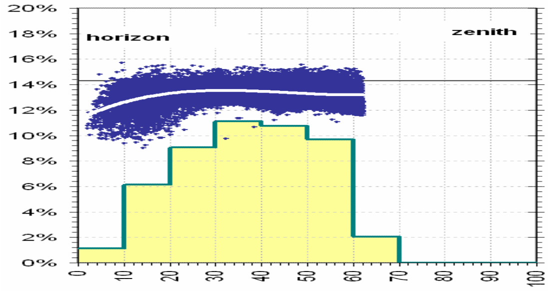

Figure 8) Module efficiency vs solar height (°) Low height to the left, zenith is 90°

Note

the very high efficiency even under high diffuse fraction (Figure 6 left)

A small drop at high angle of incidence (Figure 7 right) when the proportion of energy is small

A small drop at low solar height (Figure 8 left) only when the proportion of energy is small.

There is more energy available at high light levels, beam fractions and clearness than at low values (even in Kassel, Germany).

OPTIMUM PERFORMANCE CHECKING WITH EMPIRICAL FORMULAE

Empirical formulae for Tmodule, DC Voltage (Vdm) and DC Yield [2] have been used to compare and characterise modules and then predict the optimum array performance vs Irradiance, Tambient and wind speed, to identify faults and check for satisfactory installation [3].

Simple models of the AC system (Inverter and wiring loss, roof mounted temperatures and shading) have been used to prove good array performance or flag any downtime or other output limitations for systems like the one shown in figure 9.

For maximum energy generation it is important to check that the AC performance of an array is similar to that expected from characterising DC modules, then scaling by the numbers in series and parallel and also the limitations of the BOS components such as wiring loss and inverter efficiency.

Many third party AC systems have been studied and a variety of performance limiting effects like shading, inverter loss, turn on, and poor voltage tracking have been found and where possible minimised or eliminated.

Figure 9 shows how well the empirical equations fit the module temperature Tmodule (top red), normalised voltage Vdm (middle blue) and power YA (bottom lilac) of a system that is working well. Any deviations from these lines can be analysed to determine the cause and extent of the underperformance. There were a few dropouts due to low Voltage but all the other powers were good

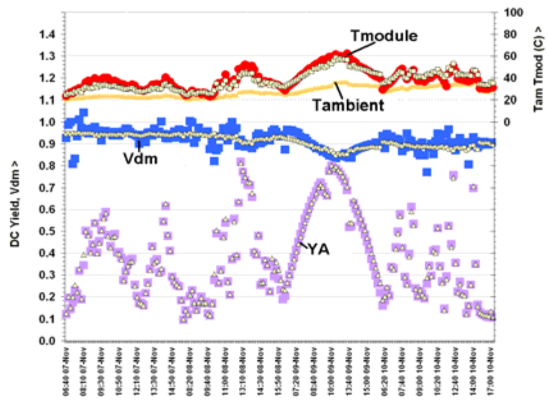

Figure 9: Measured and predicted performance of module versus time in Australia under varying weather conditions showing from top to bottom Tmodule, Tambient, Vdm, YA.

DEPENDENCE OF PERFORMANCE ON MEASUREMENT FREQUENCY

Most weather data (series of irradiance, ambient temperature and wind speed values) used in simulations comes from either hourly “Typical Meteorological or Reference Year” (TMY/TRY) series or are synthesised hourly series from Markov transition matrices. Transition matrices are tables listing the probability of changes from one weather condition to another in the next time period. They are used to generate pseudo random weather data such that the spread and correlation from hour to hour of the generated data resembles real data measured on site. However measurement data at much more frequent intervals than hourly in both Sydney (figure 3) and Kassel [4] show that averaging to hourly values distorts the actual energy versus irradiance curve and

- overestimates low light level contribution
- underestimates high light levels.

The reason is that in changeable conditions the modules will generate energy mostly during periods of bright sunshine whereas averaging sunny and cloudy periods within the same hour will suggest a lower average irradiance. In changeable weather conditions as often happens in climates like northern Europe modules often generate energy at higher than expected irradiances (due to reflections off clouds) and lower than expected temperatures (as modules cool down during cloudy periods)
Both sites showed over 6% of irradiant energy at over 1kW/m² with peak Irradiances seen at ~1.35kW/m².
Inverters sized on "expected maximum irradiances" of 0.9-1.0kW/m^2 have been seen to clip under these higher than expected conditions [4].

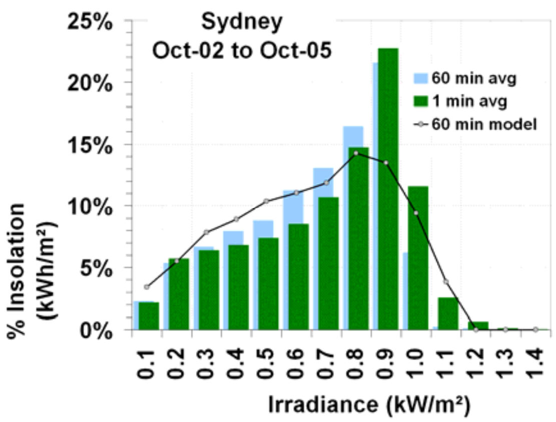

Figure 10: Distribution of irradiant energy kWh/m² vs irradiance kW/m² for a commercial hourly stochastic model (grey line) and measured hourly- (light blue histogram) and 1 minute-(dark green histogram) averaged data at Sydney, Australia. Measured data every minute 2002-2005

CONCLUSIONS

- Studies on modules such as the BP 7180 and BP 3160 confirm their good efficiencies even at low light levels and under high diffuse light conditions.

- The importance of determining the array's actual vs predicted performance under real conditions is shown to minimise BOS losses.

- The highest kWh/lifetime values are obtained from modules with high efficiency at all meteorological conditions seen by the array and with the longest guarantees (e.g. 25+ years).

REFERENCES

More than 70 of BP Solar's technical papers including all those below can be found at http://www.bpsolar.com/techpubs

[1] "4% höherer Energieertrag bei einem 83 kWp Testfeld in Deutschland-Saturn 7 Serie" / "4% Increased energy collection from 83 kWp test - Saturn 7-series" Paper (German only) Poster (English and German), Ransome et al, 21st Staffelstein 2006

[2] A Summary of 6 years performance modelling from 100+ sites worldwide, Ransome et al, 31st PVSC Orlando 2005

[3] Advanced analysis of PV system performance using normalised measurement data, Ransome et al, 31st PVSC Orlando 2005

[4] 6DV.4.32 Why Hourly Averaged Measurement Data Insufficient to Model PV System Performance Accurately Ransome et al, 20th PVSEC Barcelona 2005

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