IEEE 31st PVSC – Orlando, Florida, USA   WEDS Poster 2 A6 4.22

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Advanced analysis of PV system performance using normalised measurement data

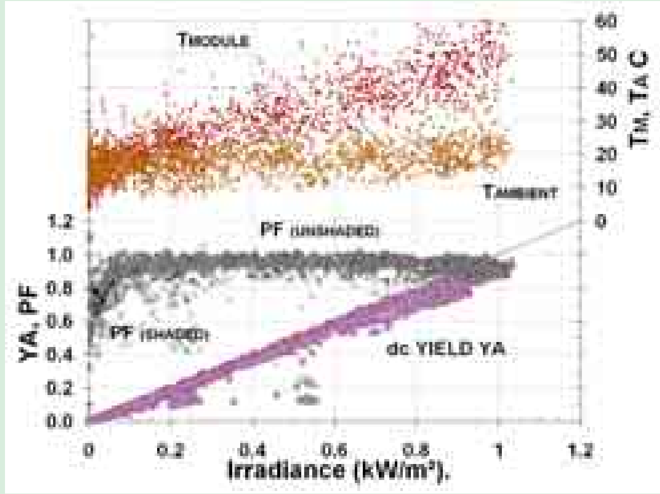
1. Introduction

- The performance of a grid connected system is usually reported by summing AC energy output over time/ nominal P_{MAX} (kWh/kWp/year) and performance ratio PR.
- Downtime, BOS faults or effects like shading need to be carefully corrected for otherwise they dominate comparative kWh/kWp values.
- A better way of characterising performance is to use the module DC yield YA and the performance factor versus plane of array irradiance G_I.
- When the module is performing well the data will be in a narrow range that can be curve fitted with empirical formulae.
- Underperforming points (which may depend on random events like outages) can be easily identified as they will not lie in this range.
- The expected yield in kWh/kWp can then be determined by folding in the curve fit to the good performance points by the expected irradiance and temperature data.

2. Outdoor measurements

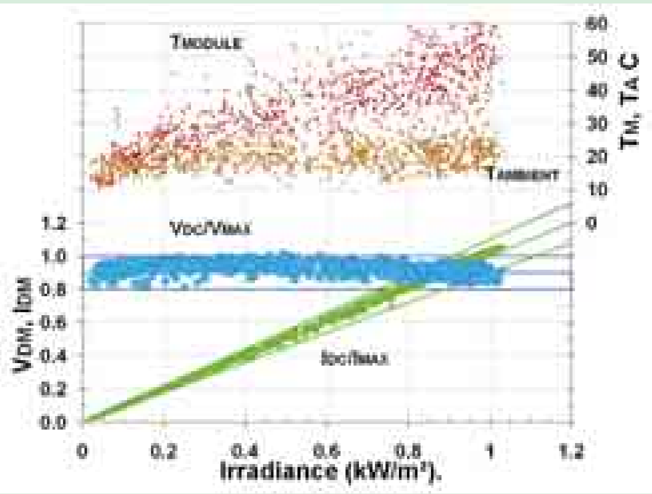
- DC Comparative module test in Sydney, Australia.
- IV swept every 30 minutes, DC measurements every minute.
- Modules taller than originally designed for were put on test late Autumn and some shading was seen early morning in mid winter (see bottom of middle row).
- The effect of this shading was studied for a few months before moving arrays further apart.

3. Characterise DC module



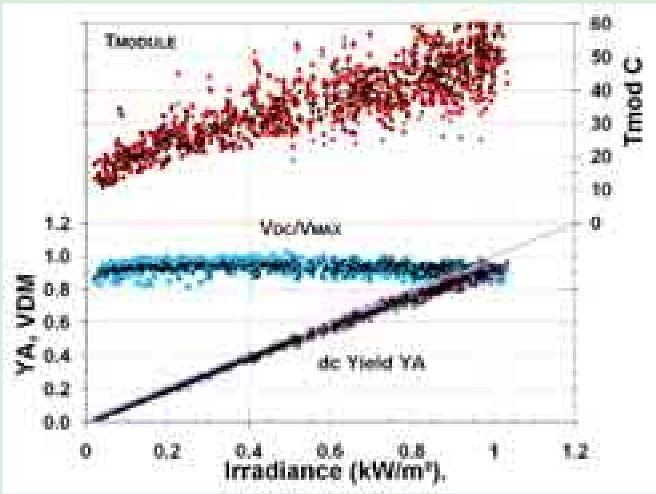
- Measurements of a BP 7180 in Sydney over the winter when shading was occurring.
- Note PF drops under low light when shading was occurring (open diamonds).
- Grey diamonds are PF when no shading.
- When unshaded there is a good, Flat PF response down to 0.05 kW/m².

4. Check voltage tracking and shading



- When shaded or other poor data had been removed, check for good module peformance.
- V_{DM} (=V_{DC}/V_{MAX}) should be 0.8-1.0 to indicate high voltage and good V_{MAX} tracking (blue limits)
- I_{DM} (=I_{DC}/I_{MAX}) should be near 1:1 line which indicates high current and no shading (green limits)

5. Empirical fits to DC module

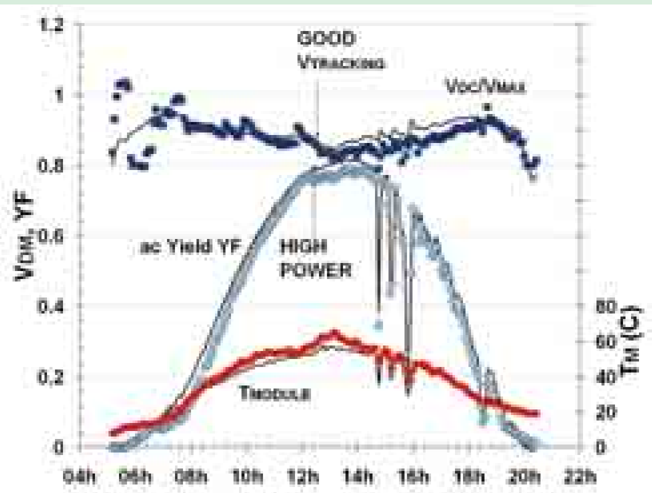


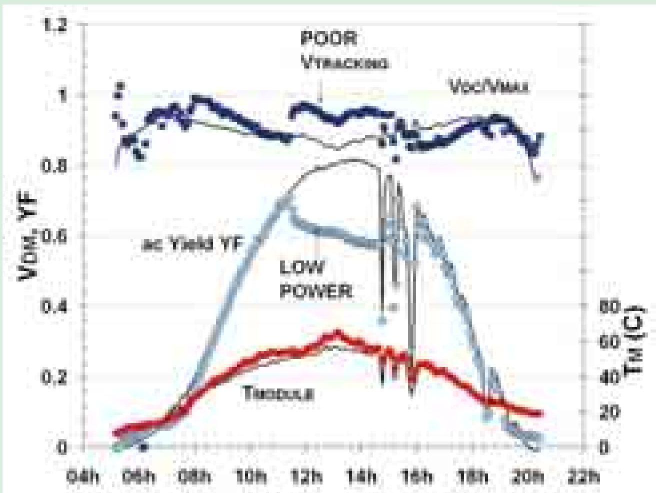
- Modules can be characterised by fits to empirical formulae
- $T_M = C'*T_{AM} + G_I*(A' + D'*WS) + E'$ (1)
- $V_{DM} = A''*LOG_{10}(G_I) + C''*T_M + D''*WS + E''$ (2)
- Yield = $\Sigma_t G_I*(A+B*\Sigma_t G_I+C*T_{AM}+D*WS)-E$ (3)
- $A = A_{SYSTEM}*A_{INVEFF}*A_{PACTUAL/PNOMINAL}*A_{STABILN(exposure)}*A_{SPECTRUM(time\ of\ year)}$ (4)

6. Model BOS and AC System

- Once DC modules have been characterised these models can be applied to large AC arrays.
- Normalised currents and voltages should be within the same range for AC arrays as for DC modules.
- For AC modelling we need to add system dependent losses for the BOS (inverters, DC wiring, mismatch etc.)

7. Model AC system – Apply DC PV model * AC and BOS losses





- Two strings in a large array in the UK were analysed. This string had good V_{MAX} tracking and its T_{MODULE} as predicted by empirical equations. It showed good yield as expected
- Another string showed glitches in V_{MAX} tracking, (much higher than expected around noon) resulting in poor current and therefore low yield.

The right hand string was later found to have a faulty fan in the inverter which was then deliberately going over voltage to stop itself overheating. Once repaired it had similar performance to the left string.

8. Parameter definitions

Abbrev-iation	Colour/ Symbol	Long name	Unit	Definition
T_{AM}	▲	Ambient temp.	°C	-
T_M	●	Module temp.	°C	-
YR	■	Insolation or Ref yeild	kWh/m²	$= \Sigma_t(G_I)$
V_{DM}	■	Normalised DC voltage	-	$= V_{DC}/V_{MAX}$
I_{DM}	◆	Normalised DC current	-	$= I_{DC}/I_{MAX}$
YA	■	DC yield	Wh/Wp	$= \Sigma_t(P_{DC})/P_{MAX}$
YF	◆	AC yield	Wh/Wp	$= \Sigma_t(P_{AC})/P_{MAX}$
PF	◆	Performance Factor (DC)	-	= YA/YR
PR	■	Performance Ratio (AC)	-	= YF/YR

9. Conclusions

- DC module performance can be characterised by measurements of performance factor PF vs irradiance, temperature and wind speed.
- Values of normalised voltage V_{DM} and current I_{DM} can be used to determine when the module is performing correctly or if it is wrongly voltage tracked or shaded.
- Empirical formulae can be used to evaluate the optimum yields of large arrays and determine any occurrences of and reasons for poor performance.

10. References

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