HOT CLIMATE PERFORMANCE COMPARISON BETWEEN POLY-CRYSTALLINE AND AMORPHOUS SILICON CELLS CONNECTED TO AN UTILITY MINI-GRID

Presented at Solar ’98, Christchurch NZ, 25-27 November 1998

Wolfgang Meike BE MIEAust CPEng NPER (Electrical)
Senior Systems Consultant
Northern Territory Centre for Energy Research
PO Box 366u, NT University NT 0815, Australia
Telephone: +61-8-8946 6884
Facsimile: +61-8-8946 6885
Mobile: +61-4-1282 7140
E-mail: wolfgang@meike.com

Abstract

The first commercial hybrid power station installation of Canon’s triple junction amorphous silicon panels is at the Power And Water Authority’s Solar Research site in the Northern Territory remote community of Jilkminggan. The site experiences regular high ambient temperatures and high humidity in the Wet Season, which is a testing environment for any new product. This paper compares the performance of the Canon product with that of the Solarex poly-crystalline silicon panels which are also installed at this site. It details the performance differences for varying temperatures and solar radiation levels. As the arrays are connected to a working mini-grid, the effects of different operating conditions on the performance of the arrays are also documented.

Introduction

The Aboriginal community of Jilkminggan (also known as Duck Creek) is located on the bank of the Roper River, around 400 km south of Darwin in the Northern Territory (Latitude: 14º57’ South, Longitude: 133º19’ East). The community has a population of over 200 people with a “small town” infrastructure of a high school, health centre, store and community council buildings.

The Power And Water Authority (PAWA) is the local generation/transmission/distribution utility in the Northern Territory. It is required to provide a reliable and continuous power supply to all Northern Territory communities above a certain size (approx 50 people, but other factors are also included), which includes Jilkminggan. In order to save fuel, a diesel/solar/battery hybrid system was installed at Jilkminggan in late 1992 to replace the old diesel only station. At that time, the community only had some 35 inhabitants and the system was sized accordingly. Both the diesel and solar capacity has been upgraded over time to match the growing energy demands of the community.

The initial hybrid power station was designed such that it would operate mainly on solar and battery power with only a limited need for the diesel power. But since the community was growing very rapidly, a different operating principal was required to maximise the savings. This is the “fuel saver” mode, which was introduced at Jilkminggan in 1996. In this mode, the solar contribution reduces the daytime peak load of the station, so as to flatten the demand seen by the diesel engines. This allows for a smaller diesel engine to be used at maximum efficiency almost all day long, instead of running a larger diesel at a much lower loading and therefore lower efficiency. In this mode, the batteries are used to supplement the solar if need be, but not for night time operation, which is achieved by the smaller diesel engine. In areas such as Jilkminggan where there is a substantial day time air-conditioning load, this

Figure 1: Overview of the Jilkminggan power station

approach is most economic. A future paper will discuss the overall station efficiency in more detail. This paper is purely concerned with the performance comparison of two types of solar panels installed at Jilkminggan.

Qty	Description	Installed	Total
1	Hino 60kW Diesel Engine		60 kW
1	Cummins 100kW Engine	Aug 1998	100 kW
1	Advanced Energy Systems 42kW, 3 phase, sine wave static power pack inverter	1992	42 kW
54	Sonnenschein Solar Block SB12/185 batteries	1992	120 kWh
7	AES Maximum Power Point Trackers	1992 – 96	21 kW_p
108	Solarex MSX-60 solar panels	1992	6.48 kW_p
108	Solarex MSX-83 solar panels	1994	8.96 kW_p
12	Solarex MSX-64 solar panels on tracking array	1996	0.77 kW_p
18	Canon GM-01 solar panels	Nov 1996	1.10 kW_p

Table 1: Installed equipment at Jilkminggan power station

Power station details

Changes to the power station configuration occurred over the years. It now consists of the equipment listed in table 1. The station runs fully automatically, without operator interference and can be remotely controlled when required via a modem connection. The two diesel engines and the inverter can all run in parallel and synchronise to the AC bus automatically as necessary. The power station has a 433 Volts three phase AC bus and is equipped with two distribution feeders for the community of the same voltage.

The total installed solar capacity is 17.31 kW_p (under manufacturer's conditions). Figure 1 above is an aerial view of the entire power station. The Solarex modules are all poly-crystalline solar panels of varying sizes. The Canon array consists of the newer triple junction amorphous silicon panels. Most of the panels are physically mounted in arrays of 18, but have varying electrical configurations to match the DC system voltage of 216 Volts via the Maximum Power Point Trackers (MPPT). All arrays have provision for adjustable north/south tilting, which is adjusted monthly to maximise the output at this tropical location. In addition, the tracking array has automatic east/west daily tracking.

Data logging system

The hybrid power station has its own control systems and limited data logging to facilitate and fine tune the operation of the station. In addition to this, there is also a substantial amount of data logging installed at the site which is dedicated to the performance monitoring of several different aspects of the station. This includes (but is not limited to) solar radiation, individual solar array current output, battery voltage, inverter and diesel engine powers and various temperatures – 40 channels in total.

The logging revolves around a Datataker DT500 logger with expansion module. A number of different transducers are used to measure the currents, voltages, powers etc. For the solar currents, Weidmüller G448 transducers are used in combination with current shunts. Vaisala SR12-E pyranometers are used for the solar radiation measurements. One is mounted on a horizontal plane, whereas the other is mounted in the same plane as the seasonal north-south tilt of the solar panels. It is the output of this latter in-plane pyranometer that is used for the results of the comparison of this paper.

Due to the electrical noise at the station and the distances involved, most of the signals between the various transducers and the logger are 4-20mA current loops. This combination of equipment has proven successful and reliable and also ensures a comparatively high accuracy of the measurements.

The transducers are scanned every ten seconds and this data averaged over a ten minute period and logged on a memory card. The data is down-loaded to the office via modem on average once a month and then analysed.

As this is an operating power station first and foremost and a solar research facility second, the control systems are programmed in such a way, as to ensure the most reliable power supply for the community as possible. This means, that the operating conditions are not always the best for the solar system performance. For example, if the large diesel engine is on line at low load, possibly due to a failure or maintenance outage of the smaller engine, then the solar output can be limited or disabled all together to ensure that a certain minimum load is kept on the diesel engine. Diesel engines suffer from glazing of the cylinder bore if insufficiently loaded (approximately less than 30% of rating). There have also been instances where some or all of the solar arrays have tripped off due to a disturbance. As the station is unattended, it may take some days or even weeks to reset such an occurrence. There was also a time where a series of "shrubs" grew to tree height and shadowed some or all of the panels in the morning and the afternoon in the Dry Season (see figure 1). As this proved unacceptable, the trees have now been kept to a height where they do not cause any negative impact on the performance of the solar plant. While this has slightly affected the amount of data available for the comparison, it has also affected the total output and/or performance of the solar part of the station. But that is the "real world" and must be taken into account in any such station. The results presented in this paper are therefore those that can be expected in any "real" and commercial power station, rather than those of a test site which simply aims to maximise the performance of a solar product.

Solar array test setup

Jilkminggan is an ideal test site for solar products, from both the customer's and manufacturer's points of view. It is hot all year round, with daily maximum temperatures hovering between 30ºC and 45ºC and night time minimums in the mid 20s in the Wet season and only rarely below 10ºC in the Dry season. In addition to this, the site has a very high humidity in the Wet season and some dust in the Dry season. This environment puts more stress on any of the equipment than most other sites, which means that if equipment survives and performs well at Jilkminggan, than one can be assured that the equipment will also work well in all other temperate to hot climates in Australia and South-East Asia. Jilkminggan is obviously not a suitable test site for low temperature tests.

The GM-01 Canon triple junction amorphous silicon solar panels (hereafter referred to as "the Canon panels") were mainly installed to allow for a direct in-field comparison with the Solarex poly-crystaline product and to also determine how the panels performed over a longer term in this environment. For the comparison, 1.1kWp were installed. The panels were supplied courtesy of Canon Japan and installed by Entech Power Systems for PAWA, who paid for the installation. The array was installed at 2m above ground, 18 panels wide and allowed to tilt from 38º north to 6º south, depending on the season. Electrically, nine panels were connected in series and those two strings connected in parallel and then connected to their own MPPT. The panels were installed on 8 November 1996, which was the first installation in the world of the Canon triple junction panels in a commercial environment. As is usual with amorphous silicon panels, the efficiency of the panels fell off during the first five to six weeks and stabilised thereafter. The results in this paper are based on the stabilised period only. Analysis of the initial degradation is not part of this paper.

One array of Solarex MSX-83 poly-crystaline panels (hereafter referred to as "the Solarex panels") was chosen for the comparison. This array consists of two rows of 18 panels, also mounted at 2m above ground and having the same tilting provisions. Electrically, twelve panels were connected in series and those three strings connected in parallel and then connected to their own MPPT. The panels were installed in 1994 and therefore were not as new as the Canon panels, but did not show any signs of degradation.

There are currently no mono-crystaline panels installed at the site to allow comparison. Nor are there any Solarex amorphous panels on site.

The panel tilt was generally adjusted once per month, at which time the panels were also washed. Both the Canon and the Solarex panels received this treatment at the same time.

For the power comparison between the Canon and Solarex panels, the output current on the DC bus side of the respective MPPT was measured in conjunction with the DC bus voltage. While this affects the overall efficiency calculations, it affects it equally for the Solarex and the Canon panels. The efficiency of the MPPT is around 96% as per figure 2 on the right.

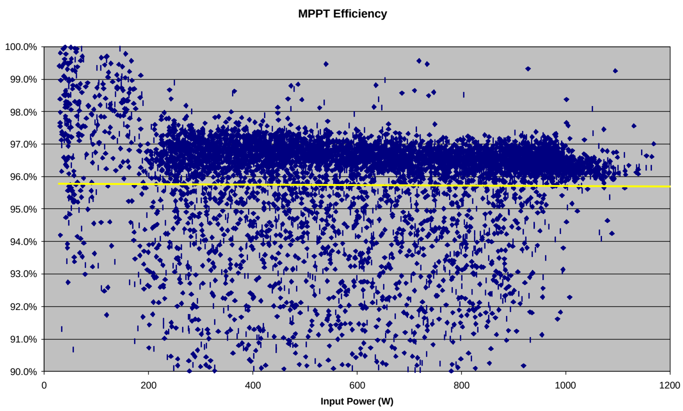

Figure 2: MPPT efficiency

The MPPT's are programmed to change from power mode to battery float charge mode once the DC bus voltage approaches 2.35 Volts per cell. This is a smooth process that begins at around 2.33 Volts per cell, but is not exactly the same for each MPPT. Only data from times when the DC bus voltage was below 2.33 Volts per cell has therefore been analysed, but even so, some slight discrepancies exist between the two arrays. Similarly, data was only analysed if the solar insolation level was above 10 W/m^2.

All the comparisons are based on the rated power as indicated and sold by the manufacturers. This figure was used in preference to some other as this is what the purchaser pays for. It is therefore the figure that affects all $/W and c/kWh calculations for future installation. In the case of the Solarex product, 83 W_p per module was used, whereas for Canon 61.3 W_p was used. As the two arrays differ in size, the figures were normalised to some common term, as described in the results section below.

To reach the conclusions as presented, data from an 18 months period was analysed. Most of the graphs shown here contain data from a three months representative period for ease of displaying the data.

Results: Array efficiency comparison

Most people when comparing performance of various solar panels, consider the cell efficiency. In some applications, the cell efficiency can have an effect on the system design and/or costs. A lower cell efficiency means that more modules and therefore a larger area is required to obtain the same power output. In solar-electric vehicles or roof-top solar designs space can be at a premium. A product with a higher efficiency cell can therefore usually generate more power over this given area. In a power station environment, land is often neither a limitation nor a cost factor. Land in outback Australia costs next to nothing. It does affect some of the balance of systems (BOS) costs, such as land preparation, fencing and the size of the support structure.

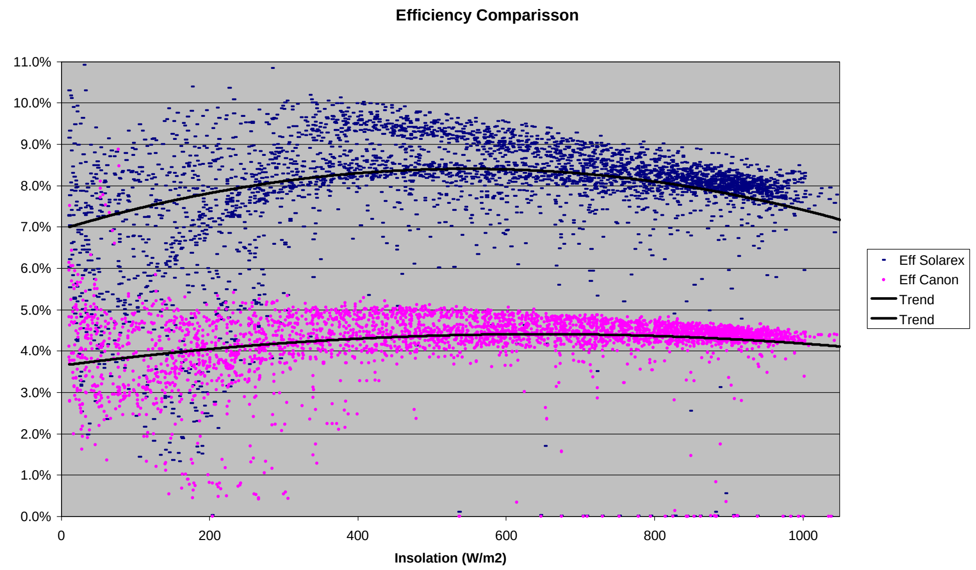

Figure 3: Array efficiency comparison

Figure 3 shows the efficiencies of the Solarex and Canon panels at varying insolation levels. The Canon array has a reasonably flat efficiency curve which lies between 4% and 5%. The Solarex array has a much more curved efficiency trend, peaking at some 9% and falling off to 7.5% at 1000 W/m^2. Remember that these figures have been calculated after the 96% efficient MPPT. Also, the array area that has been used for this purpose is the total module area multiplied by the number of modules in the array. This so obtained array efficiency is of course not the same as the cell efficiency, which would be based on only the "active" surface area. As these arrays take up as much space in the field as the individual modules, it would not be fair to only consider the active area.

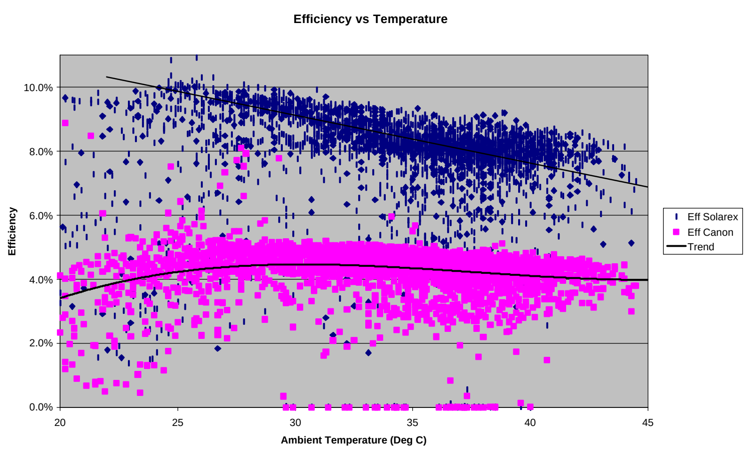

Figure 4: Array efficiency versus ambient temperature

When graphing the array efficiency versus the ambient temperature, as seen in figure 4, the reason for the Solarex's efficiency degradation at higher insolation levels can be seen. Higher insolation levels give usually rise to higher ambient temperatures and therefore higher operating temperatures. It is well known that the power output of silicon products degrades at higher temperatures. This figure indicates that the Solarex poly-crystalline material is more affected by an increase in ambient temperature than the Canon amorphous silicon material. The results below 25ºC can be disregarded, as this temperature would only occur in this environment on either an overcast day or early in the morning. Both are conditions of comparatively low insolation levels. From the graph, the Solarex array efficiency degrades from 9.9% at 25ºC to 6.9% at 45ºC, whereas the Canon array efficiency degrades from 4.7% at 25ºC to 4.0% at 45ºC ambient temperature. Most of the literature does not quote the temperature dependant cell degradation in terms of cell efficiency per ºC, but rather as % output reduction per ºC. Described in those terms, the Solarex product comes in at -1.52% per ºC and Canon at -0.74% per ºC of ambient temperature increase. This compares with a quoted figure of –0.38% per ºC of cell temperature increase for the Solarex modules.

This graph uses ambient temperature rather than cell temperature as this has been found to be the only common variable. Both, ambient temperature and solar module back-of-panel temperatures (the closest available to actual cell temperature) are being measured on site. Under identical ambient and electrical operating conditions, the back-of-panel temperatures on the Canon and Solarex modules are not the same. The Solarex modules are consistently hotter by at least a few degrees, which could be caused by different cooling properties of the glass/Tedlar combination that Solarex use compared to the steel backing of the Canon panels. This isn't clearly visible from figure 5, but this figure shows the relationship between ambient and back-of-panel temperature for the site. A large variation can be seen, probably due to varying wind conditions (wind speed is not yet being recorded on site). But in general, the following formula can be developed: back-of-panel temperature = ambient temperature x 1.42. This formula is site and average weather condition dependent.

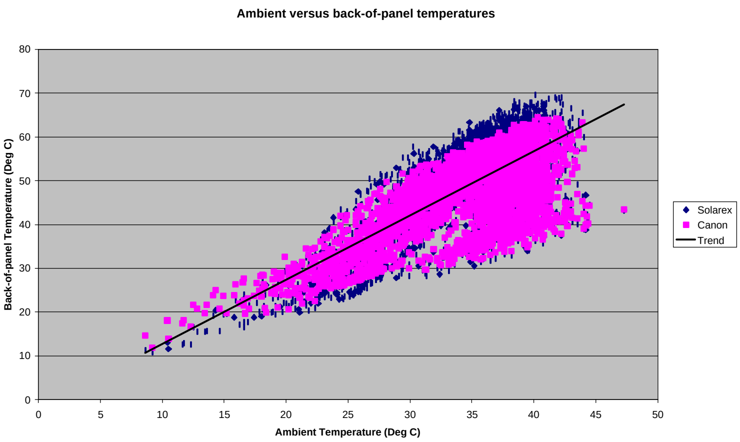

Figure 5: Ambient versus back-of-panel temperatures

Direct performance comparison

While the efficiency comparisons are interesting, the most relevant figures for any solar installation in a power station or similar, are the actual power output of a chosen solar array. Figure 6 shows this output for both the Canon and the Solarex arrays on a kW per $kW_{p\ rated}$ basis. This has been obtained by dividing the actual output of each array by the rated installed capacity, as described earlier. Over the entire range of insolation levels, the Canon array has a consistently higher output than the Solarex array. At 800 W/m^2 (ie. standard test insolation, but not standard temperature), the Solarex array outputs around 575 Watts per 1 kW_p installed, whereas the Canon array outputs close to 715 Watts per 1 kW_p. Taking into account the 4% loss in energy through the MPPT, this changes to 600 Watts and 745 Watts respectively – a substantial difference.

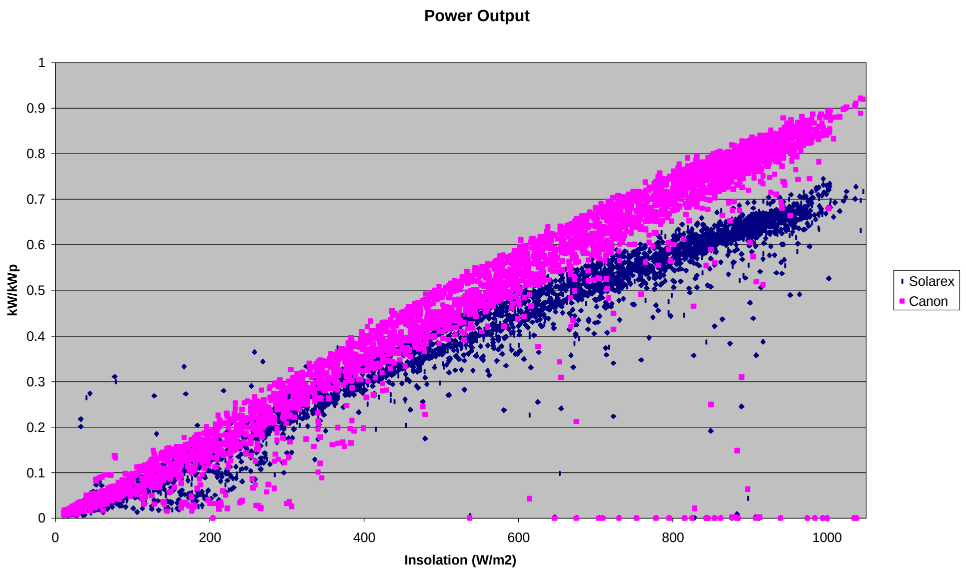

Figure 6: Normalised array power output

There are some points which are below the trend lines. This is possibly due to the MPPT changing to float charge mode in response to the station control system. While this is unavoidable, it can be seen from the small number of such points, that it has little effect on the overall solar performance or contribution.

Figure 7 gives a better indication by how much the Canon array outperforms the Solarex array. To reach this figure, the Solarex output at each instance (in kW) was taken as being 100% and the Canon output - scaled appropriately to make up for the difference in installed capacity – calculated as a relative percentage. The trend through the data indicates that the performance of the Canon array is at least 20% better than the Solarex array (between 400 to 600 W/m^2). At insolation levels above 600 W/m^2 this increases towards a 28% margin. The results at lower insolation levels are not as clear, possibly due to scattered cloud over the station, but there is also a general margin of over 20% in favour of the Canon panels.

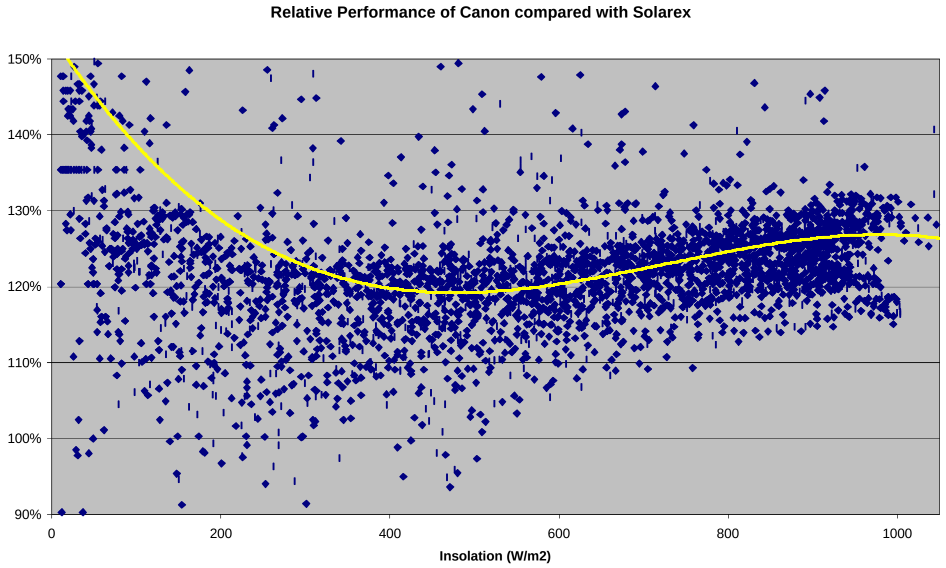

Figure 7: Canon array performance relative to Solarex array

Why is this so? The lesser temperature degradation of the Canon panel certainly contributes to this, but as the improvement can be seen across the entire insolation range - and therefore a wide temperature range -, other reasons must contribute. One such contributing factor comes from the way the modules are rated. Most solar modules are rated at standard test conditions: ambient temperature of 20ºC, solar irradiation of 800 W/m^2 and an average wind speed of 1 ms^{-1}. As poly-crystalline modules are not expected to degrade over a short period of time, they can be rated very close to actual performance. Due to the short-term degradation of the amorphous modules once they have been exposed to light, Canon actually rate their modules at around 15% less compared to their “before light exposure” performance. As the immediate degradation of amorphous modules in hot climates does not necessarily reach 15%, the user benefits. But the major part of the 20% plus gain of the Canon array seems to simply come from a better performance.

Over the period since the Canon array has reached steady-state, no noticeable degradation or substantial change in performance has been determined. The same applies to the Solarex array. But as we are potentially only looking at very small changes, they are likely to be within the error band, if they have occurred at all. A further one to two years of operation and data collection will be necessary to be able to determine this more accurately.

Physical observations of arrays

The above sections have dealt in detail with the electrical performance of the two arrays. But visual inspections have also taken place over the time period. From this, it can be concluded that both array types collect around the same amount of dust or general dirt (bird droppings etc). The Solarex modules are more prone to be damaged by shading effects casued by large spots of dirt. This is due to the nature of crystalline material.

One of the Solarex modules had to be replaced, as it failed. This is not an isolated case at the station, but something that other Solarex arrays have also suffered from (both the MSX-60 and MSX-83 modules). Possibly caused by a combination of direct thermal and electrical overheating, the Tedlar burned through in one or more spots of a module. This usually occured at the edge of a cell block, where the current carrying conductor has sharp kinks, while passing from the under-side to the top. This has been recognised by Solarex, all affected modules have been replaced under warranty and none of the replacement modules have failed so far. It is thought that the harsh environmental conditions in combination with the continuos maximised module output due to the MPPT is responsible for the failures.

While neither of the arrays under test have suffered from this, some of the other Solarex modules have been damaged by rocks that appear to have fallen from the sky, but might well have originated from a slingshot. If the glass panel is hit with sufficient force, it will crack. The Canon array is in a slightly less exposed position than the Solarex arrays that have been affected by the rocks, but the Canon modules seem much more resilient in this regard. Rocks have been found around the Canon array, but no damage is visible on the modules.

Conclusions

The Jilkminggan solar research facility is a fully operating power station, receiving a substantial contribution of its energy from various solar arrays. The station is located in a hot and humid zone of the Northern Territory and thus ideally suited to rigorous testing of solar products. Solarex poly-crystalline and Canon triple junction amorphous solar panels have been in-field performance tested side-by-side.

The results show that the Solarex product is twice as prone to ambient temperature induced output reductions than the Canon product. Based on rated peak power, the overall power output of the Canon product in the test environment is between 20% and 30% higher than that of the Solarex panels. This is a very substantial difference and needs to be kept in mind when either choosing or analysing the costs of solar panel products. This result does not means that the Solarex panels don’t work well, they just perform worse than the Canon panels when compared with their rating in this environment.

All the tests and analysis are based on real field data. No theoretical data or assumptions have been used. As the amorphous material reacts so differently to the poly-crystalline one, a theoretical comparison will never predict the actual performance nearly as well as in-field tests such as the ones described in this paper.

Acknowledgements

The author would like to acknowledge the support from the following companies and groups. Without them this paper would not have been possible.

- The Jilkminggan community, particularly Arnold Butso (town clerk) and Judy King (High School principal) for their acceptance of what was in 1992 not your “usual” power station.
- The PAWA staff that have contributed immensely over the years to this project, such as Peter Bellenger, Trevor Allwright, Mike Snell, Bob Dennis, Chris Horton and colleagues.
- Advanced Energy Systems, Perth, particularly Peter Leenhouwers and Len Wright for their feedback, assistance and Inverter upgrades
- Integrated Technical Services for their back-up of the Solarex product
- Canon Solar Produts, particularly Mr Miyazaki for providing the Canon panels and advice
- ACRE, for bringing experts in this field together and for providing a forum to discuss results and improvements

--- ooo0ooo ---