COMMERCIAL SCALE GRID CONNECTED PV: FROM THEORY TO REALITY

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Abstract – EnergyAustralia has implemented a series of grid connected PV installations, starting with a research facility, through demonstration systems to large scale commercial power stations over a period of more than seven years. In the course of this progress we have learnt that the gap between theory and reality can be quite large, the lessons sometimes unexpected and the path to commerciality very arduous.

1. INTRODUCTION

EnergyAustralia began its involvement with grid connected PV through a collaborative research project with UNSW at the Solarch site at Little Bay, NSW in 1992. Since then we have designed, installed and in many cases now own and operate a wide variety of PV installations. The installations range from one to 400kW and utilise a wide range of technologies and installation approaches. A brief overview of this progress is recounted below, including some of the salient lessons we have learned along the way.

2. IN THE BEGINNING – LITTLE BAY 1992-94

This project arose from a UNSW research project, funded by EnergyAustralia (then Sydney Electricity) with the aim of investigating the feasibility, issues and problems of establishing a grid connected PV system in the Sydney region.

The system comprises 3.6kW of panels, half BP Solar monocrystalline cells and half Solarex polycrystalline cells connected to the building's main switchboard via a flexible inverter testing system and a dedicated protection panel. It is installed in the UNSW Solarch research facility at Little Bay, in the south coastal suburbs of Sydney.

The experimental nature of the project meant the costs were tremendously high and the project timeframe very protracted. A wide range of electricity network interconnection issues were analysed and overcome, formal approval of the Minister for Energy was required to establish a private power station and the building housing the installation was constructed by the architecture faculty using student labour and mainly donated materials.

By the end of 1994, we finally commissioned the first legally grid connected solar power station in NSW.

The process had taught us much about the difficulties and institutional barriers and was the foundation for many of the changes to rules, regulations and utility practices that followed.

The facility has the ability to export excess power to the main electricity grid, and has a commercial purchase agreement in place. However, the first invoice is yet to be prepared.

3. DEMONSTRATION AND EDUCATION – FORT ST HIGH SCHOOL – 1995

Our second project was part funded by a Commonwealth Government grant as part of a joint activity again with UNSW. The concept was to place a small, grid interactive solar system in a local high school with a data connection to the school's PC system. This would enable students to gain some hands-on experience with real life data on solar power. The concept would then be rolled out to schools across the country who would see the educational value. Fort St High School in the inner western suburb of Petersham was chosen and contributed $1,000 toward the project as a sign of their commitment.

A 1kW system was commissioned in October 1995 and again provided an interesting learning experience. The challenges of installing a PV system on the rooftop of a three story building with heritage listed and no longer available roof tiles resulted in a system that, even with the government funding, cost EnergyAustralia more than $20/W installed.

Unfortunately, the university never secured funding to implement the educational aspects of the project, so no "roll out" ever occurred. The system is still owned and monitored daily by EnergyAustralia, and continues to operate satisfactorily. However the only financial return is through slightly reduced energy bills for the school.

4. DEMONSTRATION TURNS COMMERCIAL – NATIONAL INNOVATION CENTRE – JANUARY 1996

Having been involved with two small systems, we sought to develop a proposal for a larger system that would explore the issues of three phase connection. We obtained an agreement to install a 10kW system on the roof of another heritage building. This time it was the refurbished rail workshop shed at Redfern, which was about to become the National Innovation Centre – a part of the Australian Technology Park.

This time it was an all EnergyAustralia project, with no support funding from any other agency. The relatively high cost involved started us searching for a means to commercialise the activity and this became one of the kernels of the decision to create Pure Energy – the first Green Power product in Australia.

The installation comprises 126 Solarex polycrystalline 83W panels mounted on the sawtooth roof of the building. The panels face 55° West of North and are inclined at the existing roof pitch of about 30°. Inside the building an AES three phase inverter connects the system to the grid via a specialised network interconnection protection panel. Importantly, the connection is directly to the grid, rather than the building's electrical system, so that all production is metered and exported rather than offsetting usage by the building tenants.

On commissioning on 15 January 1996, it was by far the largest rooftop solar system in Australia. Installed costs remained relatively high at about $15/W. Early performance was also problematic due to ongoing problems with the inverter and the overfrequency relays on the protection panel. Once these were finally overcome, performance has settled down to a reliable, but relatively unremarkable level.

Of more interest was the potential for significant maintenance costs. Simple problem such as rusting screws in the mountings became a significant issue as changes in occupational health and safety legislation made it necessary to incur significant costs to enable maintenance crews to work safely (and legally) on the rooftop. The installation was also on the fringe of the devastating hail storm that destroyed many

Sydney roofs in April 1999. Three panels were shattered by hail impacts. Interestingly, when we came to replace them we found that some panels continued to operate despite the damage.

In August 1996, we launched the first market trials of our Pure Energy product and this installation became the first grid connected solar power station to supply electricity commercially. This commercial requirement served to focus our attention on production in a way that was then unfamiliar in the demonstration driven world of PV. This provided a new framework for our future work in PV.

5. EXPLORING RESIDENTIAL ROOFTOPS – HOMEZONE 2000 – APRIL 1996

The next project built was again part of the crossover in thinking from demonstration to commercial investment. This project was part of a display home on the NSW Central Coast owned by Hokin Homes and was the first application of a mounting frame imported from Switzerland designed to simplify residential rooftop installation. The project was fully funded by EnergyAustralia.

The installation comprised 30 Newtec 36W solar tiles installed as replacements for the normal roof tiles. They were connected via a 2kW PSA inverter to the interconnection protection panel and metering in the main switchboard at the side of the house. Again the connection was via separate metering from the house itself, so the system functioned as a mini power station.

The display home was eventually sold after about three years and the installation has been removed. During the three years, we were aware of no home buyers who seriously considered a solar PV installation as an option for their new house.

There were several problems that suggested this configuration was less than ideal. The solar tiles proved to be less simple than expected, as the spacing of the roof battens had to be altered to accommodate the different pitch of the solar tiles. The inverter was located inside a cupboard in the house and would have been too noisy had the house been occupied.

Partly due to the small scale, installed costs were high (>$20/W) and the additional costs associated with project development and approvals was significant.

6. THE FIRST COMMERCIAL PROJECT – NEWCASTLE – DECEMBER 1996

The hunt was now on for a location for a larger sized system with a friendly host and a simple development process. We thought we had found it in Newcastle City Council, who had been championing the idea of renewable energy for some time. Demand for Pure Energy was growing and we had an income to support commercial investment. We asked NCC to identify some likely candidate sites with room for about 10kW of PV, no shading and north orientation where we could install our next system. Several sites were nominated and we chose the roof of an historic railway carriage shed at Foreshore Park, Newcastle.

Unfortunately we were not yet sufficiently expert in identifying simple projects and this one dragged on endlessly – even to the point of the City Council rejecting the development application on heritage grounds.

Eventually the much re-designed project was completed in December 1996 and officially opened during a torrential rainstorm.

The installation comprises 64 Solarex 83W panels and 16 x 77W panels – a total of 6.5kW – installed on the pitched roof. These are connected via a PSA 5kW inverter to the grid via a dedicated interconnection protection and metering panel. The project was fully funded by EnergyAustralia.

Like most of the previous projects there were initial problems with inverters and monitoring systems. Our experience reinforced the importance of development costs in the overall project budget. Although this was the least expensive project to date (<$15/W installed) rooftop construction remained problematic and the cost of maintenance was looming as an issue for future projects.

7. NEW TECHNOLOGY OPTIONS – LITTLE BAY– DECEMBER 1996

During 1996 we were approached by Canon Inc of Japan regarding their amorphous silicon panels. The approach of integrating the PV material into "construction friendly" steel panels interested us so we installed a small (1kW) test array at the UNSW Little Bay research facility.

The installation is constructed on a ground mounted frame and built using conventional residential housing roof construction.

The performance to date has backed up the claims made by Canon for the panels and enabled us to develop confidence in amorphous silicon as a viable alternative which might open up a range of alternate construction options.

8. CLOSER TO HOME – HOMEBUSH – JANUARY 1996

Despite, by now, having a streamlined process for managing the legal requirements for installation of PV on buildings owned by others, the development and approvals issues were clearly a problem. Both the cost and time involved were adding substantially to project costs. We decided to look closer to home and identified an ideal rooftop in our own business park at Homebush.

This project was developed much more quickly than any of the others and commissioned in January 1997. The installation comprises 140 BP Solar 80W panels mounted on a minimal frame on the sheet steel rooftop of a cafeteria building - a total of 11.2kWp. This superseded the NIC project as the largest rooftop system in Australia. The panels are connected to the grid via an AES 10kW inverter and segregated metering.

Applying all we had learned in our previous installations, we were able finally to get clearly below the $15/W installed cost barrier, with an installation that was relatively easy to maintain and was developed in a very short time frame.

9. TO THE MARKET - BRISBANE AND WESTERN SYDNEY- 1997

Interest was growing in grid connected PV and we had completed our initial build program in support of Pure Energy, so we looked outside our own needs. We successfully contracted to build small rooftop PV systems for Austa - on the Brisbane State High School – and the Dept of Education – for three schools at Cobbity, Oakdale and the Oaks in Western Sydney. These project were completed on time, on budget and at a small profit.

The Brisbane State High School project was a 1.4kW installation, comprising 18 x 77W panels and inverter. It was completed in March 1997.

The three identical school projects near Camden were installed in July 1997 and incorporated several new (to us) design features. They used 80W PV laminate from BP Solar, rather than framed modules. Whilst this initially presented handling problems due to the fragility of the laminate, once a suitable work method was developed we had no further breakages. We also used CSA inverters and the systems were supplied with an educational package that also allowed the schools to download PV data into a PC.

10. TIME TO STEP UP IN SIZE – SINGLETON STAGE 1 – DECEMBER 1997

In March 1997, Pure Energy was released to our entire residential market of 1.3 million customers. By mid 1997, steady growth in customer numbers had led to a requirement for more solar energy. This time we were looking to build a 200kW system – ten times larger than any previously built in Australia. We elected to build on a greenfield site and looked for a location where sun conditions were favourable and development consent would not be a problem. Discussions with Singleton Council identified a suitable site and we began design and development work.

Approval was not straightforward. The consent required an environmental impact assessment and some very serious consideration of the potential for reflections to impact on the adjacent air field and cemetery operations. Finally we were granted consent and construction began.

Time was of the essence and several design decisions had more to do with speed than elegance. The installation comprises 3,456 Solarex 60W (=207kWp) framed modules mounted on galvanised steel frames covering an area of 1.25 hectares. One PSA 50kW inverter, three PSA 4kW inverters and 33 CSA 4kW inverters connect to the 11kV grid via a dedicated 200kVA pole mounted transformer.

We chose to use a diversity of inverter arrangements to test different approaches. While this has provided a lot of useful technical information, it has proven less than ideal commercially. The Sustainable Energy Development Authority assisted us through a low interest loan for a portion of the cost of the project.

11. BIGGER AGAIN – SINGLETON STAGE 2 – JULY 1998

Continuing demand for Pure Energy led us to expand the Singleton project to double the size just six months later. Our experience on stage one placed us well to improve the second time around, and we cast the net wide in search of improvements.

The result was an installation comprising 3,312 Canon amorphous silicon panels rated at 60W (total 199kWp) with a module profile specially designed to make construction easier, faster and cheaper. This was the first time this profile was used anywhere in the world. These were mounted on a simplified framing arrangement and feed the grid via four PSA 50kW inverters. We also incorporated a much simpler monitoring approach (that actually works).

Despite the amorphous panels requiring a larger area, the simplified mounting and wiring approach saved more than the additional framing cost, leading to a more economical overall design. Overall the project was better than 10% less expensive than the first stage and finally we achieved an installed cost clearly under $10/W. The project was fully funded by EnergyAustralia.

Performance to date has been excellent, with the amorphous panels consistently outperforming projections by approximately 10%. Stage two is also more reliable and in the last 12 months, out produced its similarly sized neighbour by 20%.

Other “innovations” include running sheep on the property to minimise landscape maintenance costs and incorporation of the system fail alarm system into the normal security alarm system.

12. MORE AMORPHOUS – MANLY HYDRAULICS LABORATORY – SEPT 1998

The experience we gained at Singleton Stage two enabled us to contract to install an amorphous based system specified for the Manly Hydraulics Laboratory. This 10kW project was the first commercial use of the Canon amorphous panels in a roof replacement situation in Australia. While some architectural compromises have reduced the productive capacity of the system, the installation was quite competitively priced and has proven the viability of steel based amorphous panels as an active solar roof replacement technology.

13. OLYMPIC ROOFTOP – SYDNEY SUPERDOME – SEPTEMBER 1999

The latest and last project in our current build program was conceived as part of our Olympic commitment. EnergyAustralia is the official Energy Partner for the Sydney 2000 Games and, in company with ABI Millennium identified an opportunity to install a significant PV component in association with one of the icon venues at Olympic Park, Homebush. The Superdome will host basketball and gymnastics during the Sydney 2000 Games.

The installation comprises 1176 Canon amorphous silicon 60W panels (70.5kWp) mounted on a steel frame integrated with the roof structure over the Banquet Hall portion of the Superdome. The panels follow the roofline, which has an inclination of about 8° to the horizontal. Nineteen 3.6kW SEA inverters are mounted under the panels on the framework and feed via a separate main to the main switchboard and thence to the grid. The solar system is entirely separate from the Superdome’s internal electrical system and operates as an independent power producer. It is the largest rooftop solar installation in Australia.

Despite an efficient and cost effective design, the demands of integration with such a complex public building proved costly. The 30 year guarantee demands for the roof skin of such a building could only be met by installing a conventional steel sheet roof under the panels, meaning the potential offset in both cost and weight could not be achieved. Further, integrating construction on such a busy, time constrained and high profile site proved very difficult and expensive. A low interest loan from SEDA assisted in coping with these problems.

Following substantial construction delays, the project was commissioned in September 1999 – one year before The Games – and current indications are that production will again exceed predictions.

14. OLYMPIC SYMBOLISM –OLYMPIC BOULEVARD TOWERS – JAN 2000

The grand concepts put forward for the public areas in Olympic Park include several initiatives of environmental significance. One of these was to populate the broad boulevard running past the major venues with a series of towers that would at once be both a strikingly aesthetic and functional. A key element of the design was to incorporate a grid connected PV system into the towers such that the energy used to light the Boulevard at night would be offset by solar energy produced during the day.

We successfully tendered for this unique project and have been proud to work with a range of suppliers and contractors to help bring the dream of the Olympic Coordination Authority (OCA) to reality.

The project consists of nineteen lighting towers, carrying a total of 1520 BP Solar laser grooved laminates (6.8kWp per tower). These are connected via six inverters per tower to the main electrical supply to the public area and are expected to produce about 160,000kWh per year.

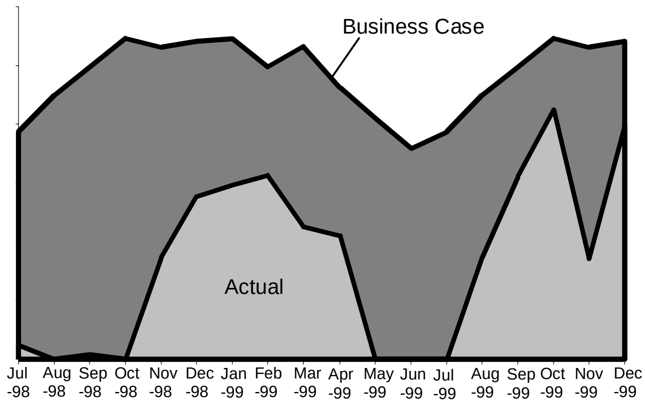
The towers represent a demonstration of innovative use of PV in public amenities and architecture. OCA was awarded an Engineering Excellence Award for the project in September 1999.

15. CONCLUSIONS

After installing $7 million worth of PV systems in many configurations, using a wide variety of different PV, inverter and installation approaches, and with a strong commercial discipline on many of the projects, we have been able to draw some conclusions about the difference between theory and reality in PV.

In the early years of our involvement, I recall a colleague doing some research work on installed PV costs. He remarked that those who had installed real systems reported a price almost exactly twice that of those who expertly predicted costs. This does not surprise me. Some observations to ponder:

- Reliability is more important than efficiency. This is the PV equivalent of the hare and the tortoise. See the graph adjacent for an example of a reputable grid connected PV system that was supposed to be a commercial operation.
- Maintenance and operating costs are always more than you expect
- Don't discount the imputed cost of rent – rooftops will not always be free.



- Project development costs are significant in large projects and crippling in small ones.
- There are hidden costs in rooftop deployment
- $/kWh produced is the only relevant target