Long Term Evaluation of New Technology Photovoltaic Modules

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ABSTRACT

A thirteen year joint program of photovoltaic research between Japan and Australia has recently concluded. Australia is one of the world's largest users of photovoltaic modules for powering telecommunications. Knowledge and understanding of lifetime performance of photovoltaic modules is therefore important in the operation of the solar powered network. The overall aim of the program was to determine what conditions affect module performance and reliability, and to provide data with which to improve the lifetime performance of new modules. The Collaborative Program has also allowed the Telstra Reseach Laboratories to research other aspects in the use of photovoltaics in telecommunications networks. This paper discusses some of the outcomes and advantages of such a long term co-operative research project.

1. Introduction

Following an agreement between the Japanese and Australian governments, a co-operative project for the evaluation of photovoltaic (PV) modules was established in early 1980. This agreement provided a framework for the co-operation between Japan and Australia for the development of photovoltaic generation systems. The New Energy and Industrial Technology Development Organisation (NEDO) of Japan was entrusted with promoting the co-operative project between both countries, while the ElectroTechnical Laboratory (ETL) of Japan, and Telecom Australia Research Laboratories, now known as the Telstra Research Laboratories (TRL), were the organisations responsible in each country for the planning and operation of this project. Japanese PV modules were supplied by NEDO to TRL for testing under unique and varied Australian weather conditions not experienced in Japan. At the same time modules were tested at TRL to determine the effects of extremes in weather on module performance and reliability. During the co-operative project various types of modules were evaluated, including crystalline silicon (c-Si), amorphous silicon (a-Si), and cadmium telluride modules (CdS/CdTe). The laboratory testing program and the long term environmental exposure program have recorded several different modes of module material degradation and loss of module electrical performance. In November 1995 it was agreed that this Collaborative Program for the evaluation of photovoltaic modules would conclude after 13 years of valuable research and productive interaction. Recently, a Consolidated Report has been released which summarises the findings reported to both module manufacturers and the scientific community [1].

2. Technology Availability

The module evaluation program ran continuously from 1982 to 1995 and reflected the changing technology of PV materials. It included the testing of single crystal and ribbon crystal c-Si modules between 1982 and 1995, first stage a-Si modules (single and triple-junction) from 1987 to 1995, second and third stage a-Si modules (tandem layer) from 1992/93 to 1995, and CdS/CdTe modules between 1993 and 1995. The module exposure history is shown Fig. 1.

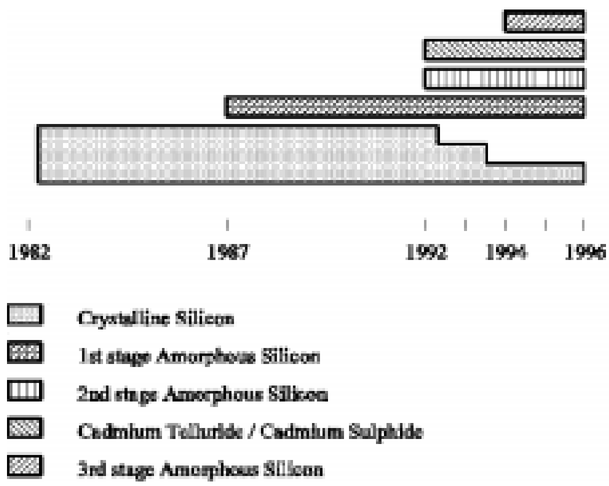


Fig.1 Module exposure history

3. Testing Program

The testing program was devised to study module degradation under different climatic regimes. This was done in two, concurrent parts, as shown in Fig. 2. One part involved real time field exposure of modules at various sites; the other involved specific, controlled laboratory testing. Aspects of each part of the test program provided complimentary elements to help in the analysis of module performance

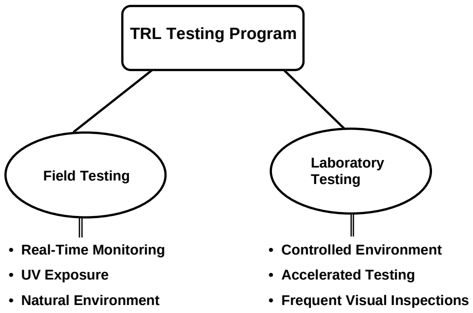
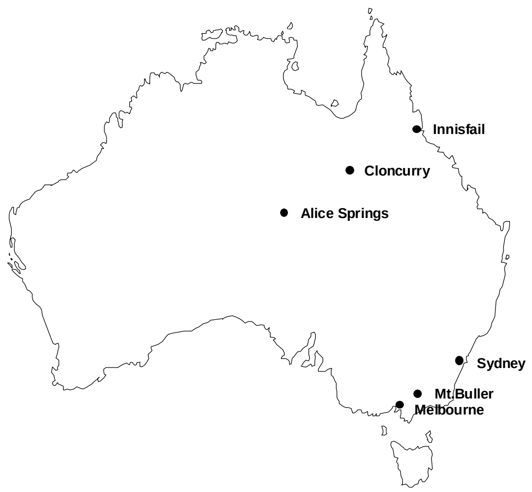


Fig.2 The test program

4. Field Sites

The field test sites established by TRL were carefully selected in areas exhibiting specific climatic characteristics. These sites were separated physically by large distances which required remote monitoring equipment at each site. The location of each field site and their associated climates are indicated in Fig.3.



Site Name	Climate	Location
Cloncurry	Hot/Dry (Original)	140°31'E 20°40'S 190m ASL
Alice Springs	Hot/Dry (Relocated)	133°36'E 23°36'S 540 ASL
Innisfail	Hot /Humid	146°00'E 17°32'S 180m ASL
Sydney	Marine	151°18'E 33°52' 80m ASL
Melbourne	Temperate	145°10'E 37°50'S 70m ASL
Mt. Buller	Cold	146°26'E 37°09'S 1600 ASL

Fig.3 Field site locations.

5. Field Module Matrix

Crystalline modules were exposed at all sites between 1982 and 1987. Some c-Si modules were used at the Alice Springs site from 1992 to 1995 as reference modules. In 1987, a-Si modules were exposed at four sites including a new cold site. In 1992, cadmium telluride modules were added to the program. By 1993, all c-Si modules (except Alice Springs reference modules) were removed from all sites. The climate-module technology matrix is shown in Table 1.

Site Type	c-Si	a-Si	CdS/CdT
Hot	✓	✓	✓
Hot/Humid	✓	✓	✓
Marine	✓	X	X
Temperate	✓	✓	✓
Cold	X	✓	X

Table 1. Climate-module technology matrix

6. Field Site Operation

The field sites were set-up with a computer data acquisition system with remote access facilities. Environmental parameters known to affect PV module performance which were measured included air temperature, black disc temperature, back plane temperature of each module and the horizontal and inclined solar irradiance.

The current-voltage characteristic (I-V curve) of each module was measured daily between the hours of 11:00 am and 2:00 pm. The solar irradiance was recorded before and after each I-V curve measurement. The module back plane temperature was also recorded before each measurement. This data was transmitted daily to TRL where it was corrected to standard irradiance and temperature. To mimimise error, only data collected during bright, stable conditions were retained.

Visual inspections of modules were of a detailed nature. Changes in the appearance of the module cells, mechanical or electrical construction of the module, or any other physical changes were recorded and photographed. Special attention was given to colour, or changes in colour of individual cells in a module. In many cases, particularly with the newer modules, it was not possible to determine the exact nature of the changes in a module while on site. In these instances the changes have been described using terminology for known changes which produce a similar appearance.

7. Laboratory Testing

The TRL laboratory test program was two-fold. One part consisted of conformance testing and module certification for Telstra’s network. The other part involved an accelerated laboratory test sequence to identify potential failure modes. This test program consisted of a modified set of laboratory tests for Class B Type II modules, with the order of the Environmental and Mechanical test sequence being a subset of tests as described elsewhere [2]. Three other tests were specifically employed by TRL to simulate exposure of module excess of 20 years in harsh Australian climatic environments. These tests were:-

Long term damp test for crystalline modules:
85°C, 85% RH, for 10,000 hours;
Long term damp test for amorphous modules:
85°C, 85% RH, for 2,000 hours;
Long term dry test:
85°C, <20% RH for 10,000 hours.

An example of the degradation in electrical performance of a module which has undergone the long term damp heat test is shown in Fig.4. Modules were examined at various stages and changes were detected using electrical performance measurements and detailed visual inspections.

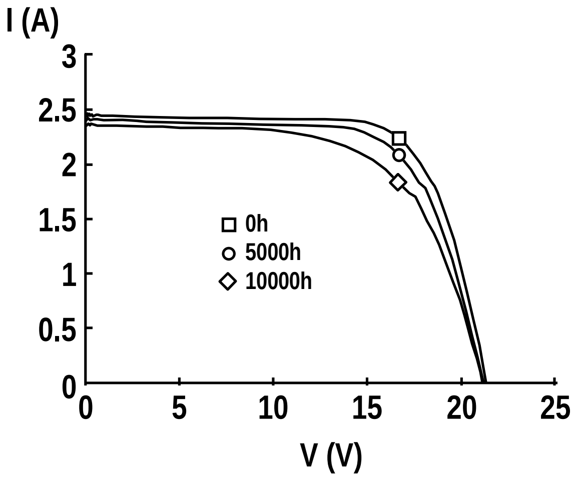


Fig.4 Degradation during long term damp test

8. Results of Module Testing Program

Both the laboratory testing and the field testing programs have been instrumental in discovering specific problems with some modules. The results allowed identification of common symptoms of module degradation. There were a few problems common in both the crystalline and the amorphous modules which affected some modules. The major ones were:

- EVA Discolouration
- Degradation in anti-reflection coating
- Discolouration of cell material
- Bubbling of rear Tedlar
- Corrosion of tracks - yellowing of solder resin

Crystalline Silicon

Over the term of the combined testing program numerous changes were observed in the modules. The main problems seen were “loss of anti-reflection coating on cells”, “delamination” or “discolouration" of the backing material or encapsulant. Some modules had loose frames but generally were of sound construction. Over eight years, the greatest power loss observed was of the order of 15%, but typically most c-Si modules exhibited power losses of around 5%.

Amorphous Silicon

The main problems seen with these modules were "cracking or breaking" of the interconnecting tracks, and marks in thin film. There was also severe breakdown of the encapsulant (EVA) in one module type during the accelerated laboratory test program. During field exposure, the a-Si modules showed a steady degradation in the I-V characteristic, with a general drop in power output annually, and some power improvement during the summer months. The greatest power loss for a particular type of amorphous modules was approximately 30%. Generally, however, over seven years, power losses were typically between 15% and 20%.

Cadmium Telluride

There was little change observed over the term of the laboratory testing program and modules exhibited power losses of typically less than 10%. Modules undergoing the field tests also changed little, with the exception of general discolouration of the cell material over the whole module. Power losses were also less than 10%, over three years.

9. Discussion

A comparison of the results of the testing programs of the a-Si and the c-Si modules found that although the c-Si material is more stable over time, it does undergo a loss of power as modules age. A major cause of this power loss is degradation of EVA, which varied between manufacturing techniques and the exposure environments. The average power loss approximately 0.7% per annum. This can be modelled to a drop of 90% over 15 years [3].

Prediction of lifetime performance of a-Si modules is much more complex. Pre-annealing of module material prior to exposure as well as seasonal changes requires extensive investigation of module performance before accurate estimates of module performance can be made. Degradation of a-Si modules has been discussed elsewhere [4].

After an initial degradation, CdS/CdTe module material appears to be stable. However, more data is required to make accurate lifetime performance estimates.

TRL’s accelerated laboratory tests are estimated to be equivalent to greater than 20 years of field exposure. Results to date from the real-time, long term field exposures broadly verify these laboratory predictions.

10. Conclusion What have we leant

The Collaborative Program has been extremely valuable because it has provided a means to obtain and compare data of module performance in uncontrolled environments with results of module performance from controlled laboratory tests.

The extreme temperature and humidity conditions in the accelerated laboratory test sequence placed modules in conditions which they would never experience in Australia. However, these tests are repeatable and allow direct comparison of module performance. High temperature conditions coupled with direct radiation from the sunlight cannot easily be simulated indoors. Performance degradation caused by these condition is best determined from real-time field exposure. The great benefit of the Collaborative Program was the concurrent collection of both field and laboratory data which allowed the development of a predictive model for solar module performance.

This co-operative project has also allowed TRL to explore and investigate other related issues concerning photovoltaic modules. Some of these investigations have been reported elsewhere [1] and include :-

i. temperature annealing of a-Si modules
ii. a-Si performance prediction
iii. spectral response changes in multi-junction cells.

It is important to note that the results and data from this work have gone back to Japan to improve manufacturing quality and techniques. Finally, this program has been instrumental in helping establish the Australian PV industry.

11 Acknowledgments

Telstra would like to thank the Japanese Government, in particular its people within its agencies of NEDO, ETL, PVTEC and JQA for their co-operation and exchange of technical knowledge during the past fifteen years. Telstra wishes also to acknowledge the valuable contribution by all the Japanese manufacturers connected with this project, and the assistance of the Australian government during the project

The permission of the Director of Research, Telstra Research Laboratories to publish this paper is also acknowledged.

12 References

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