Prediction of Seasonal and Long Term Photovoltaic Module Performance from Field Test Data

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ABSTRACT

The New Energy and Industrial Technology Development Organization of Japan, together with Telstra Corporation of Australia, have recently concluded a 15 year project studying photovoltaic module degradation under laboratory and outdoor field trial situations. During this period crystalline silicon modules have been exposed at outdoor field sites since 1982. Thin film photovoltaic technologies have been studied since 1987.

Field exposure of nearly 14 years shows a linear reduction in maximum power in crystalline silicon-based modules, occurring mainly through a reduction in Fill Factor. Exposure in hot and dry, and temperate climates indicates climate has little effect on the rate of degradation. Seasonal variations in the performance of different amorphous silicon modules have been determined using a solar simulator. Empirical models describing both seasonal and long term behaviour have been developed. Good agreement between observed and predicted behaviour is obtained

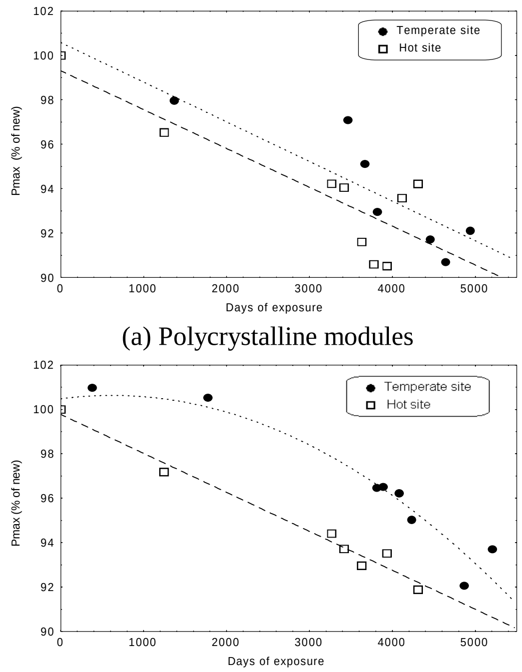
1. Introduction

A total of thirteen different types of modules, crystalline silicon (c-Si), amorphous silicon (a-Si) and CdS/CdTe, were exposed outdoors in different climates for durations up to 14 years. At each field site two modules of every type being studied were exposed, and their individual current-voltage characteristic (IV curve) measured each day, conditions permitting. Weather conditions were continuously remotely monitored, and sites visited regularly to observe any physical changes in the modules. Throughout this period the IV curves of selected modules were also determined under standard laboratory conditions using the Telstra Research Laboratory solar simulator.

2. Analysis of field test data

<u>Crystalline Silicon Modules</u>

The change in maximum power (P_{max}) for two different technology c-Si cell modules over approximately 13 years exposure in both temperate and hot, dry climates is shown in Fig.1. The modules in Fig.1(a) used polycrystalline ribbon cells encapsulated in silicone resin with Tedlar backing. The other module type used 10cm single crystal cells, also encapsulated in silicone resin.



(a) Polycrystalline modules

(b) Single crystal modules

Fig.1 Degradation in crystalline Si modules

Although there is some scatter in the data, several observations can be drawn from Fig.1:

- the rate of degradation for three of the four modules was constant, approximately 0.7%/year,
- the degradation rate is similar for both module types,
- the rate of degradation did not significantly differ for exposure in the two climates.

The reduction in P_{max} has occurred primarily through a decrease in the Fill Factor. The degradation of the single crystal module at the temperate site appears non-linear over the exposure period. The cause of this behaviour has not yet been determined. Analysis of degradation in other modules at the sites is required to confirm the above observations.

Field testing of 35 commercial silicone encapsulant modules for 8½ years exposure indicated a mean degradation rate of 0.4% pa in P_{max} and 0.1% pa in short circuit current (I_{sc}).. In 1994 an extensive 440 module sample field survey of the modules in use by Telstra, manufactured before 1990, indicated a larger degradation rate in I_{sc} for EVA encapsulated modules [1]. The field-based measurements were associated with greater uncertainty, but the typical lifetime to 80% of rated I_{sc} was estimated to be approximately 15±3 years. The survey also indicated that batch related problems (such as changes in material composition or component and construction quality) can be a greater risk to power system reliability than gradual degradation in performance.

<u>Amorphous Silicon Modules</u>

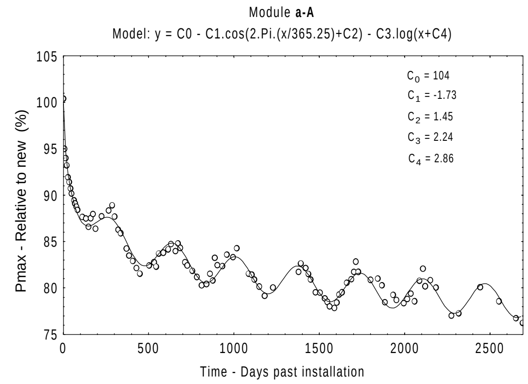
Simple models describing the underlying long term degradation in a-Si performance have been reported [2]. The variations in P_{max} attributable to seasonal annealing, though not completely symmetric, have been described using a cosine function of the form given in equation ***1***. The number of days of exposure is given by **t,** while $\mathbf{C_2}$ is a phase angle to allow for the time of the year when the modules were installed. Long term degradation is described by a logarithmic term.

$$P_{max} = C_0 - C_1.\cos(2.\pi.(t/365.25)+C_2) - C_3.\log_e(t+C_4) - \quad \mathbf{\mathit{1}}$$

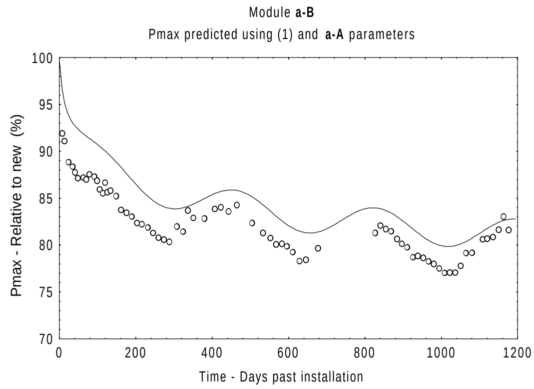
The seasonal variation was observed to be approximately constant for any one module at a given site. The fit of the model to the data, illustrated in Fig.2(a) for module **a-A** which utilizes single junction cells, is generally very good. Regressed coefficients for **a-A** are provided in Fig.2(a).

The degree of seasonal improvement in P_{max} caused by thermal annealing is given by $\mathbf{2.|C_1|}$. Although sufficient data were not available to draw general conclusions, it was found that the amount of annealing was smaller for the triple junction module compared to the single junction module of the same vintage, and was smaller still for the more recent tandem cell module.

A key requirement of any model is the ability to predict the values of independent data. Module **a-B** is of the same type as **a-A** but was installed at the same site 18 months later. Fig.2(b) compares the estimated and measured P_{max} data for **a-B**, using the parameters derived for **a-A** and the appropriate change in $\mathbf{C_2}$. The model predicts the behaviour of **a-B** well except at the very beginning of exposure. It is possible that the longer hours of sunlight during summer caused a more rapid initial degradation in P_{max} of **a-B** than occurred for **a-A** which was initially exposed in winter (fewer sunshine hours), despite the higher average temperatures which in subsequent years of exposure aid the annealing process. It is also evident that $\mathbf{C_2}$ alone is not sufficient to fully account for the time of year when a module is installed, and a better version of ***1*** is required.



(a) Fit to measured data



(b) Predicted behaviour in independent module

Fig. 2. Measured and predicted values of P_{max}

3. Conclusions

Field testing of PV modules has provided significant data on which reasonably reliable performance degradation models have been developed. The degradation rate of c-Si modules is almost constant, while a-Si modules show a logarithmic decrease in P_{max} with an approximately sinusoidal seasonal variation.

4. Acknowledgments

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5. References

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[2] I.J. Muirhead, “Long term performance modelling of amorphous silicon photovoltaic modules”, Proc. PVSEC-7, Nagoya, Nov 22-26 1993, pp461-462.