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LONG TERM DEGRADATION OF PHOTOVOLTAIC DEVICES UNDER REAL OUTDOOR OPERATING CONDITIONS

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ABSTRACT

Performance losses in photovoltaic (PV) systems are a major impact on the financial viability of photovoltaic energy. The degradation rate ($R_D$) of photovoltaic (PV) modules/systems is expected to be affected by the location of where the devices are installed, which will present different levels of different stresses. In this paper, a database is established by collecting the $R_D$ of PV modules/system from different locations based on literature from 1986 to 2011. A statistical analysis of the $R_D$ of the selected PV modules is presented. The correlation between their degradation and environmental strain doses are also investigated.

1. INTRODUCTION

The financial viability of PV systems depends on a variety of factors, but a major factor is the ageing of the devices. In order to understand the magnitude of this, a database is established to evaluate reported degradation rates $R_D$. These reports are mostly limited on power. A summary of the identified reports is given here.

Fig. 1 Map showing the location of investigated modules/system

Data collected ranges from 1986 to 2011, currently including 440 modules and 77 systems in total. All of these modules have been exposed outdoor for at least one year and annual degradation rates have been extracted. Fig. 1 presents the geographical locations demonstrating a wide spread from 145°E to 157°W for longitude and from 59°N to 37°S for latitude. Diverse climates are included: desert, mountain continent, tropical, moist maritime, temperate, Nordic and arid hot climate etc.

Fig. 2 summarises the $R_D$ of different modules/systems currently in the database, grouped by their cell types. The x-axis represents the years of operation, the y-axis are reported degradation rate. $R_D$ are mainly between 0% and 4%/a. The average $R_D$ is different for different cell types, i.e. sc-Si:-0.71%; pc-Si: -0.63%; unspecified c-Si: -0.6%; a-Si: -2.09%; other thin film: -1.68%; system: -1.21%. It should be noted that many of the thin film reports are on developmental systems and/or include the initial degradation commonly observed e.g. in a-Si devices. About 78% of c-Si solar cells have $R_D$ dominantly between 0%-1%, which is in agreement with the assumption that this is less than 1%/a [1].

It is noticeable that some systems show negative degradation if operated for a few years. This can be attributed to power distributions within the installation. The performance of several CIGS modules is also slightly improved, which is considered to be due to the effect of light soaking.

2. DEGRADATION AND ENVIRONMENTAL STRESSES
2.1 Environmental Doses

This section aims to analyse location dependence of ageing. The analysis is limited to wafer based devices, as a larger statistical sample exists. Stresses are estimated through the corresponding meteorological details (ambient temperature, total irradiance on inclined surface of modules and relative humidity) as calculated by ‘Meteonorm’ [2].

According to Arrhenius equation [3], the irradiance dose \( (d_G) \) and relative humidity does \( (d_{RH}) \) can be defined:

\[
d_G = G \exp\left(-\frac{E_a}{RT}\right)\tau_t
\]

(1)

\[
d_{RH} = RH \exp\left(-\frac{E_a}{RT}\right)\tau_t
\]

(2)

In these equations, \( E_a \) is determined through a numerical approximation procedure and 25kJ/mol is assumed for all devices in this study.

2.2 Degradation Rate and Irradiance

Fig. 3 shows the correlation between \( R_D \) and irradiance dose for wafer based devices. The \( R_D \) is average value of selected modules in each location.

![Fig. 3 Correlation of \( R_D \) and irradiance dose](image)

As shown in Fig. 3, the \( R_D \) scatters, but trend that \( R_D \) increases with increasing irradiance does can still be identified. As \( R_D \) is negative, results show a negative irradiance coefficient of around -0.000063. Considering the model given in [4] that the ageing effect of 1% increase in relative humidity was equivalent to that of 1°C rise in temperature, the degradation is investigated based on the temperature and humidity model. Results show that the modules that degrade above the linear line have smaller combined values than those under the linear line. Modules above the linear line have a value in the range of 50 to 60. Besides that, there are still exceptions whose deviation can further be attributed to the differences in technologies and number of years of exposure.

2.3 Degradation Rate and Humidity

The relationship between \( R_D \) and relative humidity dose for crystalline silicone solar modules are depicted in Fig. 4. As shown, the \( R_D \) increase with the increasing humidity does. There still exists certainty variation which may be caused by the differences like irradiance, temperature, module types etc. A negative coefficient of around -0.0005 is identified.

![Fig. 4 Correlation of \( R_D \) and humidity for crystalline silicone solar modules](image)

3. CONCLUSION

The analysis of the database since 1986 shows the long-term degradation rate of PV modules/system is typically in the range of 1%-4%/a. The results indicate the influence of environmental conditions on module performance. With the increasing of environmental dose, the degradation rate rises. However, the correlation of ageing rate and single environmental stress is not strong which indicates that the estimated activation energies are not optimal. Furthermore, degradation depends on complex combined factors of outdoor environment and technology. This database will be extended and more detailed analysis will be presented in the future to reveal a clearer correlation between degradation and environment.

REFERENCES


