Establishment of a PID Pass/Fail Test for Crystalline Silicon Modules by Examining Field Performance for Five Years

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Executive Summary

In an experiment with five module designs and multiple replicas, we found that crystalline silicon cell PV modules that can pass the following criterion—less than 5% power degradation in stress test conditions of 60°C, 85% relative humidity (RH), 96 h, and nameplate-rated system voltage bias—show no power degradation by potential-induced degradation (PID) in the range of 4–6 years duration in the Florida, USA environment. These data suggest that this chamber stress level is useful as a pass/fail criterion for PID, and it will help ensure against degradation by system voltage stress in Florida, or less stressful climates, for at least 5 years.

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Introduction

The potential-induced degradation mechanism occurring by shunting and junction failure (PID-s) has been studied in depth since 2010 [1,2]. However, IEC 61215, the "Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval" standard, currently does not contain a PID test. The technical specification IEC TS 62804-1, "Photovoltaic (PV) Modules – Test Methods for the Detection of Potential-Induced Degradation – Part 1: Crystalline Silicon," was published to define test methods for evaluating PID in crystalline silicon PV modules. Table 1 shows two the test methods defined with three levels each as follows:

Table 1. Stress levels in IEC TS 62804-1, Photovoltaic (PV) Modules – Test Methods for the Detection of Potential-Induced Degradation – Part 1: Crystalline Silicon.

(RH: relative humidity; Vsys: maximum system voltage indicated by the module nameplate)

Testing in damp heat using an environmental chamber
60°C / 85% RH / + and – Vsys, 96 h
65°C / 85% RH / + and – Vsys, 96 h
85°C / 85% RH / + and – Vsys, 96 h

Testing in dry heat using an Al foil cover for grounding
25°C / <60% RH / + and – Vsys, 168 h
50°C / <60% RH / + and – Vsys, 168 h
60°C / <60% RH / + and – Vsys, 168 h

In both methods, Level 1) corresponds to severities that represent the minimal stress levels for detection of PID whereas Levels 2) and 3) are provided for use if further acceleration or stress is desired.

In 2013, several publications provided results of chamber stress tests that included some of the conditions listed in Table 1, with comparisons to field PID testing in the range of 6 month to around 2 years duration [3,4]. These results showed that the 60°C, 85% RH, module rated system voltage in negative polarity (-Vsys) condition successfully differentiated seven module designs. Those modules that significantly degraded in the test also failed in the field (four types). The modules that sustained power through the test (greater than 5%) did not exhibit PID-s in the field to the extent tested (three types). Additionally, some relationships between the chamber tests and Al foil tests were presented [**Error! Bookmark not defined.**].

However, it is not clear to what extent passing these levels with less than 5% degradation—a usual level for the pass/fail criteria in the IEC standards for PV modules—means for field performance over the long term. This paper therefore presents a comparison of accelerated tests and extended-duration field tests for aid in determining appropriate levels for establishing module resistance to PID-s in the field.

Experiment

Five types of conventional 60-cell multicrystalline Si ($n^+/p/p^+$ front-junction) modules were tested for PID in multiple replicas in chamber tests at 60°C with 85% RH, with module nameplate system voltage in negative polarity applied to the shorted module leads. Strings in negative polarity have been associated with the PID-s mechanism [**Error! Bookmark not**

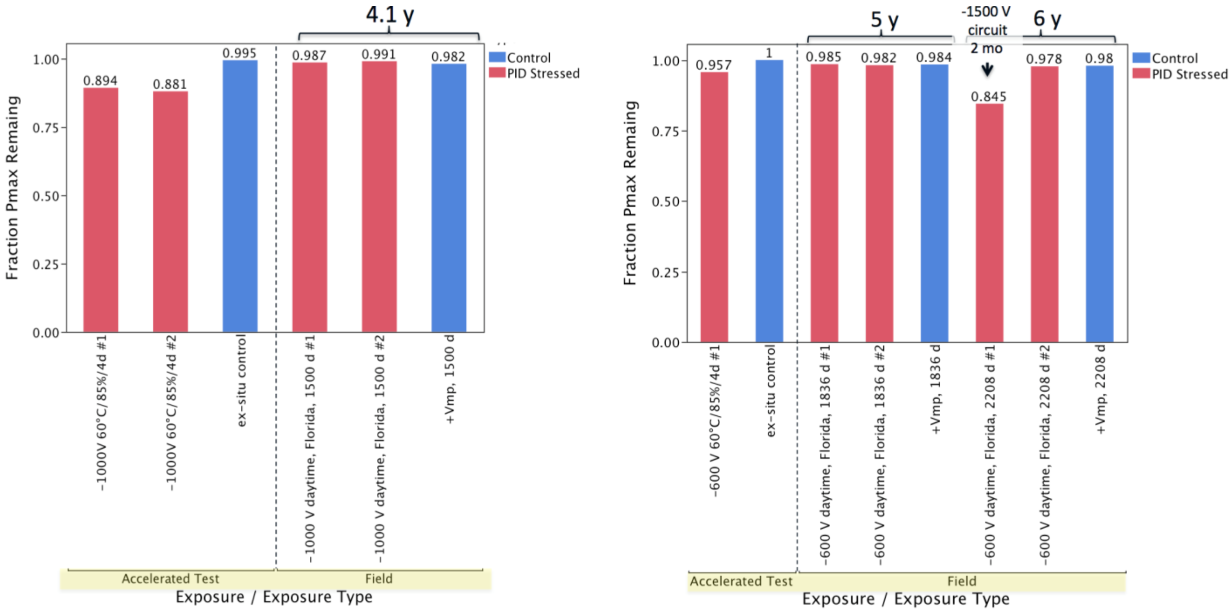
defined.]. The module's mounting points were connected to ground through a leakage-current detection circuit. In some cases, module power (P_{max}) monitoring during the accelerated lifetime testing was achieved using the previously described technique of superposition employing dark current-voltage (*I-V*) curves obtained *in-situ* within the chamber [5]. Power (P_{max}) at standard test conditions (STC) of the modules was also measured with a solar simulator during the course of stress testing.

Replicas of the above-discussed module types were placed in Florida, USA—a hot, humid, subtropical environment near the Atlantic Ocean coast—also applying nameplate system voltage in negative bias during hours of sunlight to simulate array voltage. The replicas were placed near to horizontal to replicate a flat roof-mounting scenario. Information about the system has been previously published [**Error! Bookmark not defined.**,**Error! Bookmark not defined.**]. Salt mist and some water pooling on the modules after rains provide conductive paths from the module face to ground for extended periods, which drive PID-causing ionic (largely Na^+) charge transfer into the silicon solar cells. This environment thus provides for a relatively stressful natural environment for understanding the limitations of these modules' resistance to PID. Depending on the module, P_{max} of the modules was either measured periodically on a flash tester after dismounting the module or measured directly on the mounted module with an *I-V* tracer using an electronic load, in which case the measured curves were adjusted to STC power.

All module power measurements were normalized to their post-5 kWh/m^2 light-soak values to remove light-induced degradation from the calculations. Relating the environmental-chamber-accelerated PID tests to the outdoor tests, we seek to determine primarily how the 60°C/85%/-Vsys chamber condition serves to evaluate PID resistance in the field.

Results and Discussion

Figure 1 shows the results of two module types tested through the conditions of 60°C, 85% RH, 96 h, and -Vsys in chamber and under system voltage bias in the field. Figure 1(a) shows that degradation of the first module type in the chamber stress test was on average 11% relative, whereas the two modules of this type that were exposed in the field under system voltage bias of -1000 V did not degrade compared to the unbiased control measured over a period of 4.1 years.



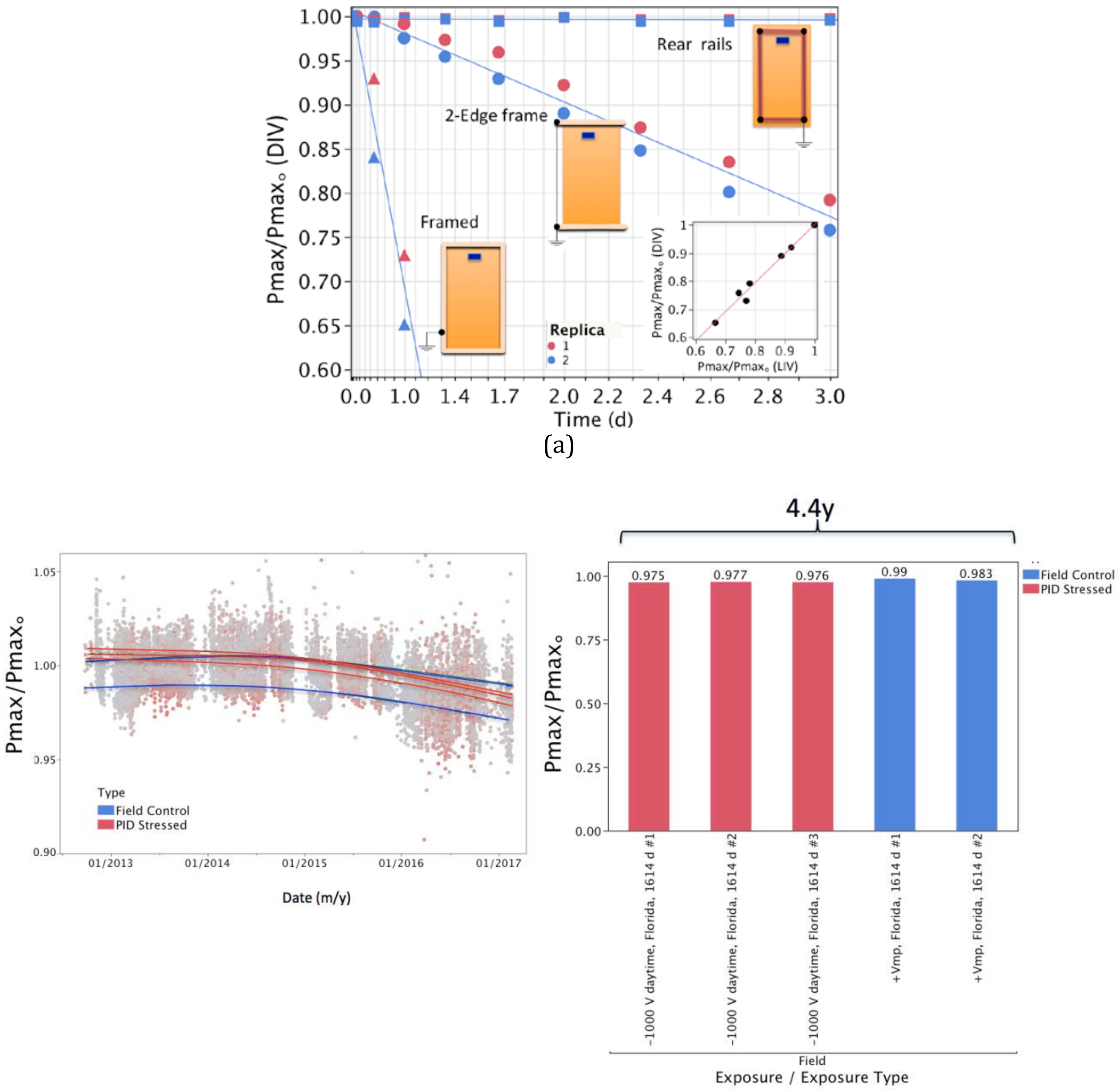
(a) (b)

Fig. 1. Comparison of power remaining through chamber tests (60°C, 85% RH, 96 h, and module rated system voltage in negative polarity) and field tests of 4.1-yr duration, (a); and 5- and 6-yr duration (b). In (b), one module in the field had the bias increased from -600 V (its rated system voltage) to -1500 V for 2 months, in which case degradation was seen. The stressed modules are shown with respect to controls placed in the chamber and field without applied voltage bias.

In Fig. 1(b), a single module is seen to degrade about 4% relative in the chamber stress test by PID, whereas two replicas biased at their rated system voltage (-600 V) outdoors in the field for 5 years have not degraded. In the sixth year, one of the modules was biased at 2.5 times its rated system voltage and degraded as a result. The other, which was normally biased, did not degrade over the 6 years.

These two module types seen in this experiment suggest that if a module passes the 60°C, 85% RH, 96 h PID stress level with –Vsys applied with less than about 5% degradation, it will not exhibit measureable power loss due to PID degradation within about 5 years of being deployed in the field environment. It is also seen that this chamber stress level is not an over-stress because the module type will degrade in the field if the applied system voltage is exceeded.

Figure 2 shows the performance of three additional module designs. They are of a single laminate type but with three different kinds of frame and mounting configurations. In Fig. 2(a), we see that, depending on the mounting, the degradation rate differs in the chamber stress tests. The type with insulating rear rail mountings does not degrade in the chamber over the course of the 22-day stress test at the level of 60°C, 85% RH, 96 h, and module rated system voltage in negative polarity. Results for the outdoor tests are shown in Figs. 2(b) and 2(c), where it is seen that the module type under bias mounted with rear insulating rails does not show significantly different degradation in power compared to the controls for the 4.4-year period. It has been previously published that the other module types that degrade in the chamber with full or two-edge frames degrade by 5% in power (relative) in the field within about two months and seven months, respectively [**Error! Bookmark not defined.**].



(a)

(b) (c)

Fig. 2. (a) Module design with three mounting configurations subjected to PID in chamber tests. (b) Power degradation of the type with rear insulating rails over time, and (c) after 4.4 years shown with respect to field-mounted controls without bias.

We cannot be confident that all crystalline silicon module types will exhibit the same acceleration factor for PID shunting between the test condition and the use condition. Significantly differing module designs from the conventional designs examined here may exhibit differing behavior. Florida is a humid, subtropical environment, bordering the "warm temperate" and "equatorial" regions according to the classification of IEC 60721-2-1, "Classification of Environmental Conditions – Part 2-1: Environmental Conditions Appearing in Nature – Temperature and Humidity." So evidence may eventually emerge to suggest that a harsher test would be useful for the more stressful environments, for example, tropical rainforest. Work is in progress to collect such data [6].

On the other hand, modules usually experience significantly lower voltage stress than nameplate rated system voltage, which was applied in tests herein. Reasons include that strings are specified for their lowest operating temperature, often leading to a 10% to 25% reduction in system voltage of the array at its actual operating temperature [7]. Additionally, modules maintained at their maximum power will experience an approximately 18% lower string voltage during their operation compared to the open-circuit condition for which they are rated. However, when the inverter is at different operational states such as powered off, waiting for PV (e.g., start–up), clipping, and during utility outages, the voltage will be higher. If modules rated for 1500 V system voltage are used, they usually experience less than half that with respect to ground considering the maximum input voltage of 1500 V for ungrounded transformerless inverters rated for IEC low-voltage applications. Actual system voltages are further reduced in times of low irradiance.

Summary and Conclusion

Five module types were tested under 60°C, 85% relative humidity, 96 h, and module rated system voltage in negative polarity condition to examine PID shunting. Replicas were placed in the field under their rated system voltage as well. We found that modules that can pass with less than about 5% degradation at these test conditions do not degrade by PID in the field (Florida, USA) in an evaluation of about 5 years duration. Considering the relatively hot, humid, sea-salt-containing environment of Florida, we suggest that this test criterion is sufficient for evaluating resistance to PID-shunting in crystalline silicon modules for use in the continental United States.

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