Effects and recovery of Potential Induced Degradation (PID) in Solar Panels

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Potential induced degradation (PID) is a well-known phenomenon that is one of the biggest problems faced by solar panels in general, and solar cells specifically. PID causes significant power losses to solar cells, impacting their development. PV panels can have a positive or negative bias based PID effects, this depends on the grounding of the panels in the field. This paper examines the difference between the two polarities and how they affect the panels' performance. The panels in reverse bias have shown to be more resistant than those in forward bias. Reverse bias panels on average have lost 1.54% average maximum power compared to a more significant 5.31% average power loss in forward bias. The percentage losses for 600 hours of PID is very significant as explained in the IEC1804 Standard. In this paper, Electrical recovery was done, the results were promising as after 200 hours of reversing the polarities on the panels, the forward bias panels were able to recover 2.42% of the average power lost in the PID effect part of the experiment, while the reverse bias panels however showed less progress at 0.37% average recovered power.

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I. INTRODUCTION

As solar energy gets more and more important, Photovoltaics (PV) systems are now using high voltage systems in order to supply more electrical energy and harvest additional energy from the sun. This requires solar panels to be connected serially, allowing for the voltage and power of the panels to be additive, making it feasible to have extra energy harvested. For safety procedures, the frames of each individual module are grounded. However, differences of up to 1000 volts can result in an individual string on the PV cells with respect to the frame[1]. This phenomenon is the PID (Potential Induced Degradation) effect. This phenomenon results in power output losses from the solar panels which can result in power loss up to 30%, due to the leakage of electrical current from the solar cell to the frame of the panel. The voltage bias that occurs between the cell and the frame causes the negative ions to diffuse away from the semiconductor material towards the glass or the frame. Moreover, positive ions mainly Na+ ions from the PV glass is mobilized and travels through the encapsulant (EVA) towards the PV cell[2-4,5]. The voltage bias between the cell and the frame can be either positive or negative, this depends on the grounding of the frames and is different for each company, manufacturer, and users. The physical mechanism on the cell level has been introduced and explored extensively by Dr. Volker Neumann[5,8]. Dr. Neumann performed an experiment on mini modules in a climate chamber at damp heat conditions, 85°C and 85% humidity. His experimental method was different in a way that he had to cover his mini modules with an aluminium foil, which was connected to a high positive voltage while the cell is on earth potential. Electroluminescence (EL) images of the mini modules were acquired, which showed the formation of shunts just below the busbar. To further investigate, scanning electron microscopy (SEM) and electron beam induced current (EBIC) which were used to identify shunts, particles and recombination active regions.

In this paper, we test five panels for PID in positive and negative bias in order to assess the severity of losses when the solar panel is subjected to positive or negative bias. Two panels are tested in forward bias (+1000V) to the PV cell, and two panels are in negative bias (-1000V) to the PV cell,

the 5th panel is neutrally biased and is there in order to have a fair comparison of the results. The panels are tested by means of a flash tester in order to measure the maximum power that can be produced from the solar panels. The maximum powers among other parameters are compared in order to further understand which bias affects the solar panels more.

This paper focuses mainly on p-type silicon based solar panels. The IEC62804 draft was used in order to have a test standard for our results[4,9].

II. EXPERIMENTAL PREPARATION

Several factors affect PID, the main factors affecting the panels' performance are the humidity and temperature the panels are exposed to. Increasing the temperature and humidity can accelerate the degradation of the performance of the PV panels. Thus, while testing the panels, the panels are subjected to high temperature and humidity alongside a positive or negative voltage bias of 1000V in order to accelerate the effects of PID[7].
As mentioned, five panels in total were tested, two in the positive direction (+1000V) and two in the negative direction (-1000V). The average power of the panels in each direction was taken and plotted.

A. Induced PID test

The testing was performed in an environmental chamber at 60°C (± 2°C tolerance) and 85% relative humidity (± 5% tolerance) for 600 hours. The modules were taken out regularly every 100 hours in order to check the power max losses and check for any visual defects that might have occurred during the 100 hours. Every 100 hours, the panels were tested at the flash tester under standard test conditions (STC). The most important aspect of the flash results were the power max changes, however tables in the upcoming section will present the deviation of the panels' short-circuit current, open-circuit voltage and fill factor. This will then be compared in order to show the effects of PID on each of these parameters.

A positive or negative voltage is supplied by one power supply supplying a voltage either to the cell (for negative bias) or to the frame (for positive bias).

B. Electrical Recovery

To explore the recovery of solar panels, the panels that were subjected to a forward bias were subjected to a reverse bias at the same humid and hot environment (85% humidity, 60°C), and vice versa for the reverse bias panels. This is an "electrical recovery" process, where the panels are subjected to a voltage bias of the polarity opposing to the polarity they were subjected to in the induced-PID effect part of the experiment.

III. RESULTS

The results section serves to show how the panels reacted to the PID effect in each voltage bias, followed by the electrical recovery process, and the percentage of power we were we able to recover from the panels as a result of this electrical recovery process.

A. Induced PID

For the PID effect, the panels were subjected to 600 hours of 1000V, in the positive or negative direction for 2 panels in each direction. The panels were tested under STC, by means of a flash tester in order to measure the different parameters of the panels and understand how P_{max} changes as the number of hours of PID increases. The lab was kept at temperature between 22-26 degrees and humidity between 40-50%, in order to have a fair comparison between all panels after each 100 hours of PID.

Table I. Neutral tested solar panel parameters, after every 100 hours.

PID hours	V_{oc}/V	I_{sc}/A	R_{series}/Ω	R_{shunt}/Ω	P_{max}/W	Fill Factor %
0	46.45	9.21	0.48	82.97	334.74	78.20
100	46.41	9.19	0.51	100.15	333.06	78.09
200	46.39	9.23	0.53	77.41	331.71	77.50
300	46.42	9.19	0.52	92.54	331.96	77.83
400	46.34	9.22	0.50	87.54	331.91	77.71
500	46.23	9.21	0.53	71.11	329.77	77.42
600	46.24	9.22	0.53	75.37	329.88	77.38

Table II. Reverse bias solar panel parameters, after every 100 hours.

PID hours	V_{oc}/V	I_{sc}/A	R_{series}/Ω	R_{shunt}/Ω	P_{max}/W	Fill Factor %
0	46.35	9.27	0.51	72.63	333.05	77.51
100	46.27	9.29	0.52	66.39	331.45	77.11
200	46.32	9.27	0.51	65.39	330.96	77.08
300	46.30	9.29	0.53	64.19	329.88	76.69
400	46.25	9.26	0.53	70.35	329.60	76.68
500	46.18	9.25	0.54	65.07	327.32	76.67
600	46.18	9.27	0.56	73.61	327.99	76.64

Table III. Forward bias solar panel parameters, after every 100 hours.

PID hours	V_{oc}/V	I_{sc}/A	R_{series}/Ω	R_{shunt}/Ω	P_{max}/W	Fill Factor %
0	46.24	9.18	0.52	122.31	328.43	77.39
100	45.94	9.14	0.51	121.07	324.76	77.33
200	45.77	9.08	0.50	105.99	321.79	77.40
300	45.66	9.06	0.56	101.31	318.12	76.90
400	45.62	9.05	0.58	85.64	318.08	76.66
500	45.39	9.03	0.60	73.53	311.04	76.40
600	45.32	9.01	0.64	65.85	311.86	76.38

As tables I-III show, the value for V_{oc}, I_{sc}, P_{max} and Fill Factor have dropped as the number of hours of PID increase. Specifically, the forward bias panel has shown a much higher degradation in terms of its characteristic parameters. These will be discussed more in depth in the discussion section. Moreover, R_{series} has increased in resistance as the panels stay longer in the environmental chamber.

The open-circuit voltage (Voc) is the maximum voltage available from a solar panel, which occurs at open-circuit (zero current)[6]. The short-circuit current (I_{sc}) is the current going through the solar panel when the PV panel's voltage across our PV panel is zero (i.e. short circuited). The short-circuit current is the largest current which may be drawn from the solar panel[6].

Fill factor (FF) is the ratio of the maximum power that could be drawn from the solar cell to V_{oc} and I_{sc}. The series resistance (R_{series}) in a solar cell has to be typically very small in value.

Low shunt resistance (R_{shunt}) causes power losses in solar panels by creating another current path for the light-generated current to move through in the solar cell. Such a diversion reduces the amount of current flowing through the solar cell junction and reduces the voltage from the solar cell[6]. Ideally, the value of R_{shunt} should be as high as possible (infinite resistance).

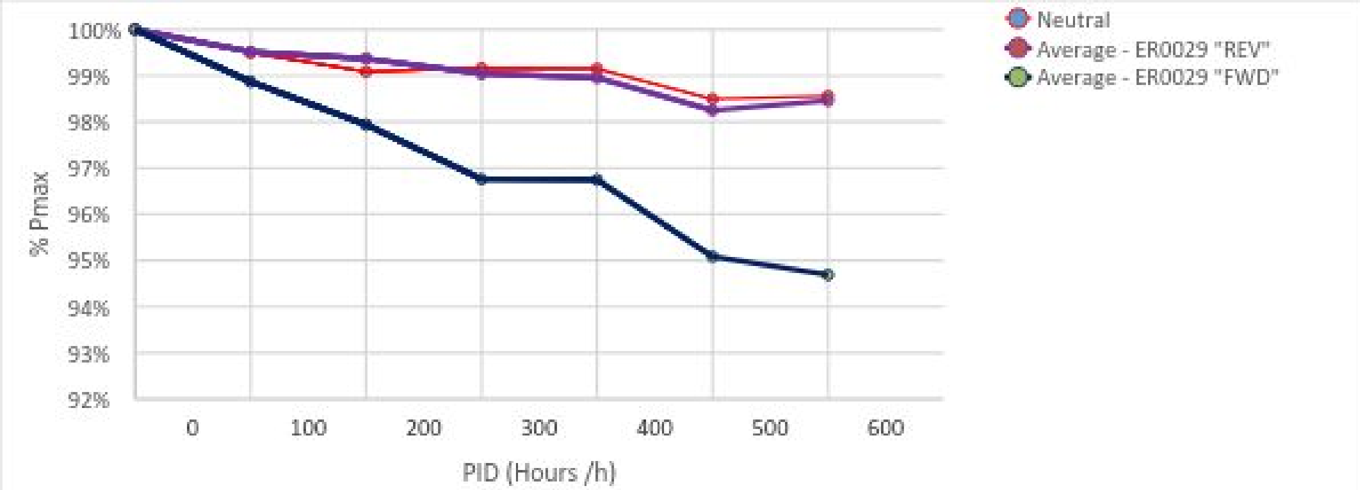

Figure 1. $\%P_{,max}$ vs the PID hours that the solar panels have spent in the environmental chambers. The average power loss of the reverse bias solar panels is plotted alongside the forward bias panels and the neutral panel. The plot shows how more significant the forward bias (+1000V) is on the panel compared to reverse bias (-1000V). Forward bias panels have lost approximately 5.31%, while neutral and reverse have each lost 1.44% and 1.54% respectively.

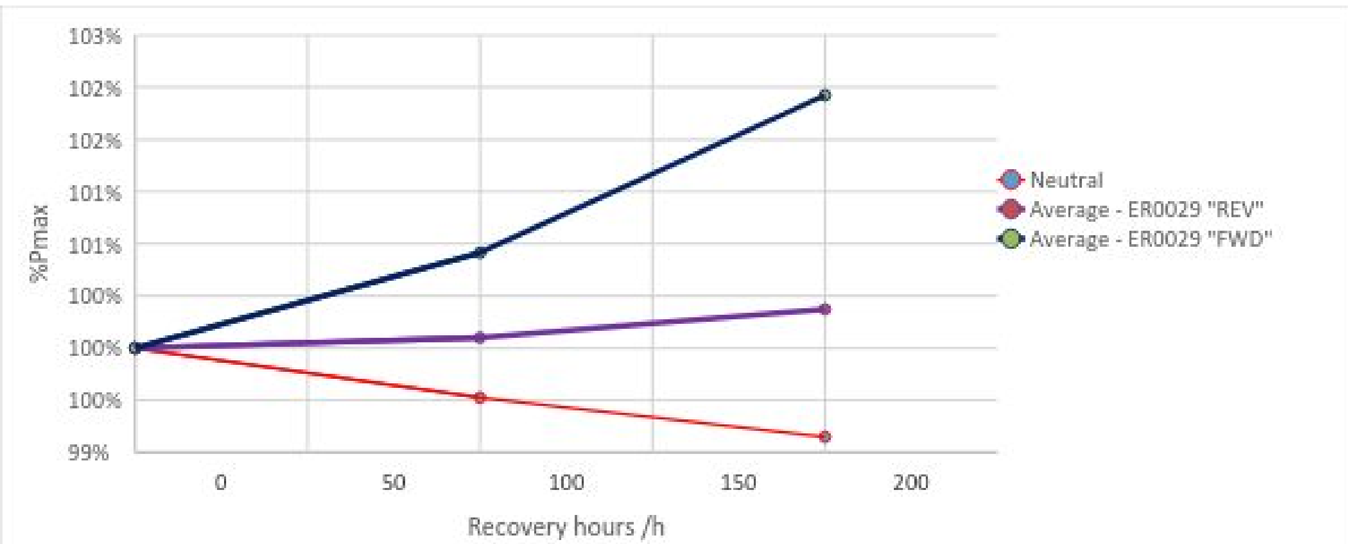

Figure 2. The electrical recovery process is plotted for the reverse and forward bias panels. The forward bias panels have shown a great improvement in terms of gaining back a fraction of the power that it has dropped in the induced PID part of the experiment. The forward bias panels have gained back approximately 2.42% of the power it has lost in the induced PID. This is more than 40% of the P_{max} it has lost. Reverse bias panels have not shown a similar success, only gaining back 0.37% of the power lost, which is about 25%.

B. Electrical Recovery

The electrical recovery process starts with the reverse bias modules going into the environmental chamber in forward bias (+1000V), and vice versa. The panels are still labelled as their original testing in part a.

Tables IV – VI present the characteristic parameters of our solar panels for reverse, forward and neutral bias configurations. The results from the tables, show that the panels are able to recover a percentage of the lost power in the induced PID part.

Table IV. Neutral tested solar panel parameters, after every 100 hours.

PID hours	V_{oc}/V	I_{sc}/A	R_{series}/Ω	R_{shunt}/Ω	P_{max}/W	Fill Factor %
0	46.24	9.22	0.53	75.37	329.88	77.38
100	46.11	9.19	0.51	70.40	328.14	77.30
200	46.07	9.17	0.50	65.50	326.51	76.40

Table IV presents the data for the neutral PV panel. The panel continues to degrade even further as the panel is now under DH (Damp-heat) conditions. The neutral panel is there to ensure that the voltage plays a huge role in the degradation and the recovery of our panel's performance.

Table V. Reverse bias solar panel parameters, after every 100 hours.

PID hours	V_{oc}/V	I_{sc}/A	R_{series}/Ω	R_{shunt}/Ω	P_{max}/W	Fill Factor %
0	46.18	9.27	0.56	73.61	327.99	76.64
100	46.48	9.28	0.55	77.45	328.07	77.84
200	46.55	9.28	0.52	81.46	329.28	78.01

Table V is the reverse bias PV panels characteristic parameters. The solar panel was able to recover 0.37% of the total power that has been lost in the induced PID part 1.54%. The panels performance and characteristic parameters are slowly recovering after 200 hours of electrical recovery.

Table VI. Forward bias solar panel parameters, after every 100 hours.

PID hours	V_{oc}/V	I_{sc}/A	R_{series}/Ω	R_{shunt}/Ω	P_{max}/W	Fill Factor %
0	45.32	9.01	0.64	65.85	311.86	76.38
100	45.94	9.06	0.57	65.85	315.16	77.33
200	46.14	9.11	0.54	108.65	319.45	77.40

Table VI is the forward bias PV panel's characteristic parameters. The most promising PV panel was the forward bias panel, it was able to recover 2.42% out of 5.31% that was lost in the induced PID part. The panel's performance in theory should get better with an increase number of hours of electrical recovery.

IV. DISCUSSION

As presented in figure 1, the %P_{max} vs the PID hours the panels have gone through in the environmental chambers. The results show that the forward bias panels have shown much greater degradation in terms of performance with the power lost averaging 5.31% of the total starting power from the panels. This is a significant loss as Table III shows as well, V_{oc}, I_{sc} and FF have been dropping as we have been going through with our experiment. V_{oc} has dropped from 46.24 to 45.32, 0.92V difference which is very significant. I_{sc} has dropped from 9.18 to 9.01, FF has also dropped by 1%, from 77.39% to 76.38%. These values all correspond to the P_{max} drop that the panels have suffered. Moreover, R_{series} has gone up from 0.52 to 0.64Ω. These results correspond to the mobilization of Na ions and their motion from the PV glass and diffusion in our semiconductor material creating a stacking fault. At the stacking fault, electrons and holes are more bound to recombine causing the power of our panels to drop significantly.

However, as the electrical recovery process started for our experiment, the panels have shown an improvement in all of their respective parameters as well as the power gained back. Forward bias panels have shown great recovery, recovering 45% of the power lost in the induced PID step. The panels were able to recover 2.42% out of 5.31% power lost in the first step of the experiment. This is well explained in a paper presented in the 4th international conference on silicon PV in 2014 about the sodium outdiffusion from stacking faults in the recovery process[5]. The paper explains how after an electrical recovery process; the Na ions are diffused from the stacking faults back into the PV glass leaving no trace of the stacking fault.

Forward bias panels have been severely impacted in comparison to the reverse bias panels. This should not be a surprise as applying a positive bias to our PV panel triggers the Na ions to diffuse into our semiconductor material creating more stacking faults, which causes electrons and holes to recombine and drop our power, FF, V_{oc}, I_{sc} and increase R_{series}. R_{series} increases as a result of the stacking faults that were created, the increase of the series resistance causes problems in terms of decreasing our power output and a significant drop in our efficiency[2].

V. CONCLUSIONS

In summary, this paper examined the PID phenomenon which is very unpredictable and random in nature. Over the course of the experiment, we were able to deduce that the forward bias on our PV panels is more destructive that reverse bias. The forward bias panels had a significant P_{max} loss of 5.31%, however after electrical recovery the panels had been able to recover 2.31% of that loss. Moreover, reverse bias panels dropped 1.54% and were able to recover 0.37%, this is less significant than the forward bias. PID is unpredictable, random and depends on the framing of our PV panels for some panels to have a forward or reverse bias PID effects. Going forward, exploration of the different framing techniques study would help us understand even more how the panels would get a positive or negative PID effect.

Moreover, the different materials of our PV panel could be tested in order to find the optimum glass thickness, EVA, and cells that should be used. A lot of research could be done on this phenomenon, and this is just the beginning. The quest for clean, green energy will drive us to learn more about PID, test for it and attempt to fully recovery panels by different recovery techniques.

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Notes and references

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a)A. Ibrahim was the primary author of this paper. He conducted all experiments and wrote the manuscript.
b) R.Li has supervised A.Ibrahim's work.

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