AE Solar Energy • 20720 Brinson Blvd • Bend, OR 97701 U.S.A.
www.advanced-energy.com/solarenergy
877.312.3832 • sales.support@aei.com • invertersupport@aei.com
Please see www.advanced-energy.com for worldwide contact information.

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APPLICATION NOTE

Mitigating Panel Polarization

CONTENTS

Introduction

Potential Induced Degradation (PID) is an undesirable property of some solar modules. The factors that enable PID (heat, humidity, and voltage) exist on all photovoltaic (PV) systems, but the effect does not occur on all or even most PV systems.

New PV plants should be designed with modules that are resistant to PID. Because resistant modules can add system costs, it may be necessary to look at alternative ways that mitigate PID, with relatively inexpensive changes to the system.

This Application Note highlights options for mitigating PID using Advanced Energy inverters. The options discussed here are not always required for proper system functionality, however, and should therefore be assessed on a case-by-case basis. Additional information about the causes and effects of PID can be found in *Understanding Potential Induced Degradation*, a white paper published by Advanced Energy.

Designing PID-Resistant PV Plants

While environmental factors cannot be controlled, the site of the PV plant is an important consideration in designing for PID resistance. Testing has demonstrated that hot, humid conditions increase the likelihood of PID becoming a problem. Drier, cooler climates, by contrast, have a relatively lower risk of experiencing PID. It is important to note, however, that what constitutes "hot" and "humid" varies by module, and even drier and cooler locations may occasionally experience conditions favorable to PID.

Crystalline silicon (c-Si) modules are available that have been engineered to be resistant to PID. These modules generally use more expensive encapsulants, optimized Anti-Reflective Coating (ARC) processes or other design choices that give them a premium price. Given the declining prices of c-Si modules, designing a new PV plant today involves a cost trade-off between the modules and the balance of system. For modules which are susceptible to PID, polarity restrictions are sometimes specified by the module manufacturer, however these may have an adverse impact on plant profitability and performance efficiency due to the need for grounding kits and isolation transformers.

It is important to note that although the configuration of the inverter is a factor in designing a PV plant, "[m]any years of experience with numerous systems provide a clear and reassuring answer: for panels with crystalline solar cells, there is no interrelationship between potential panel degradation and the inverter principle used." [1]

System Mitigation Options for PID

For PV systems with c-Si modules that are susceptible to PID, Advanced Energy offers two options to mitigate the degrading effects. Where the module manufacturer has a polarity restriction and stipulates a specific ground reference, Advanced Energy offers the TX series of inverters. These inverters are monopolar, and the array can be grounded either positively or negatively. TX inverters are available in a wide range of sizes, from 35 kW to 500 kW.

Where the module's PID mechanism is known to be reversible, often referred to as "Surface Polarization" or the "Polarization Effect," Advanced Energy offers a Charge Equalizer kit for the NX series of inverters (600V models 250NX, 333NX, and 500NX; 1000V kits will be available by mid-year). The NX series enables the Equalizer to work in systems needing either a positive or a negative charge reversal. Applying a voltage bias to modules has been tested and proven in practice to reverse the adverse effects of ion mobility caused by the Polarization Effect.[2]

If modules need a reversal of negative polarization, for example, the Equalizer applies a +600V bias to the negative side of the array at night when the array is off. The power consumption of the Equalizer depends on module capacitance and leakage current, but is a maximum of only 3.5mA at 600V. Figure 1 shows a block diagram for an Advanced Energy 500NX inverter equipped with the Equalizer.

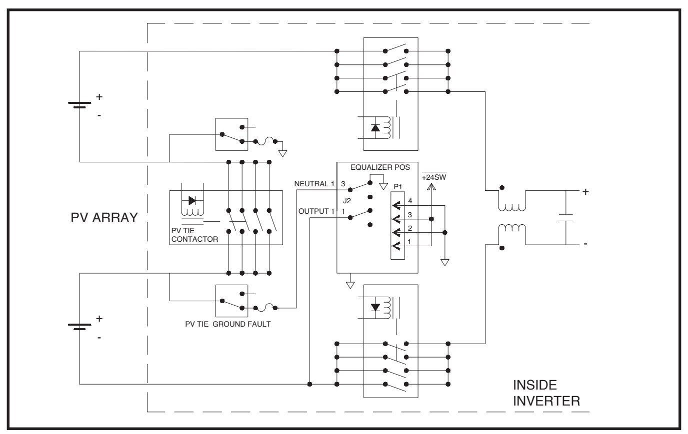

Figure 1 - The Advanced Energy Equalizer applies a positive or negative voltage bias overnight, as necessary, to reverse the Polarization Effect in the modules.

The inverter measures the array voltage to manage Equalizer activity. In the configuration shown in Figure 1, the inverter enters a standby mode in the evening when the combined voltage of both arrays drops below ~660V. The inverter then enters a sleep mode at ~100V, which is when the Equalizer is designed to operate. After entering sleep mode, the inverter turns on the Equalizer to apply a +600V bias to the negative array. Because the negative array is now biased at +600V and the positive array is now at ~0V, the result is a purposefully asymmetric array.

The ground fault sensing in the inverter remains on even while the inverter is in sleep mode, which will result in an "asymmetric array" fault code being issued, and this serves as an indicator of proper Equalizer functionality rather than a ground fault. Such an asymmetric array fault occurring above 100V when the inverter is active (or in standby mode and has recently been on) would indicate a potential ground fault condition that warrants troubleshooting.

The inverter senses voltage constantly. In the morning, when voltage begins to rise, the inverter "wakes up" when the apparent combined array voltage reaches ~200V. At this time, the inverter turns off the Equalizer, causing the apparent combined voltage to jump to ~800V, which then clears the asymmetric array fault code. The bus charging cycle begins simultaneously, and steady-state operation begins soon thereafter.

Figure 2 shows the gradual change in system offset voltage (V_{cm}) before and after applying the charge equalizer's reversing effect. V_{cm} represents the delta open circuit voltage (V_{oc}) between the positively- and negatively-referenced arrays as measured from the neutral (center). Although other measurements are available to indicate the existence and extent of PID, V_{oc} is used because it can be measured easily by the inverter or by an ordinary volt-ohm meter.

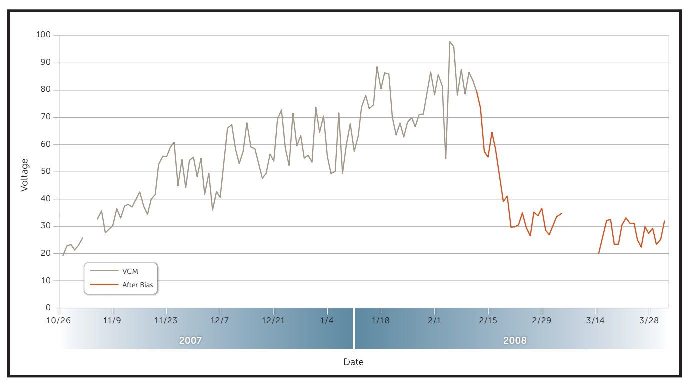

Figure 2 - Shown here is the change in offset voltage before (grey) and after (orange) installing the charge equalizer. This particular system was designed with a 20V offset.

The facility used in the test results shown in Figure 2 is a 1 MW plant in southern California that was commissioned in October 2007 with c-Si modules and AE 333NX inverters. The Equalizer was installed in early 2008 and, as shown in Figure 2, the voltage offset rapidly returned to normal. The time required to correct the issue was less than the time it took to manifest, and this is also the case for daily operation. A follow-up review of the system in December 2012 revealed that the Equalizer has continued to keep V_{cm} under 25V on a daily basis, as shown circled on the top graph in Figure 3.

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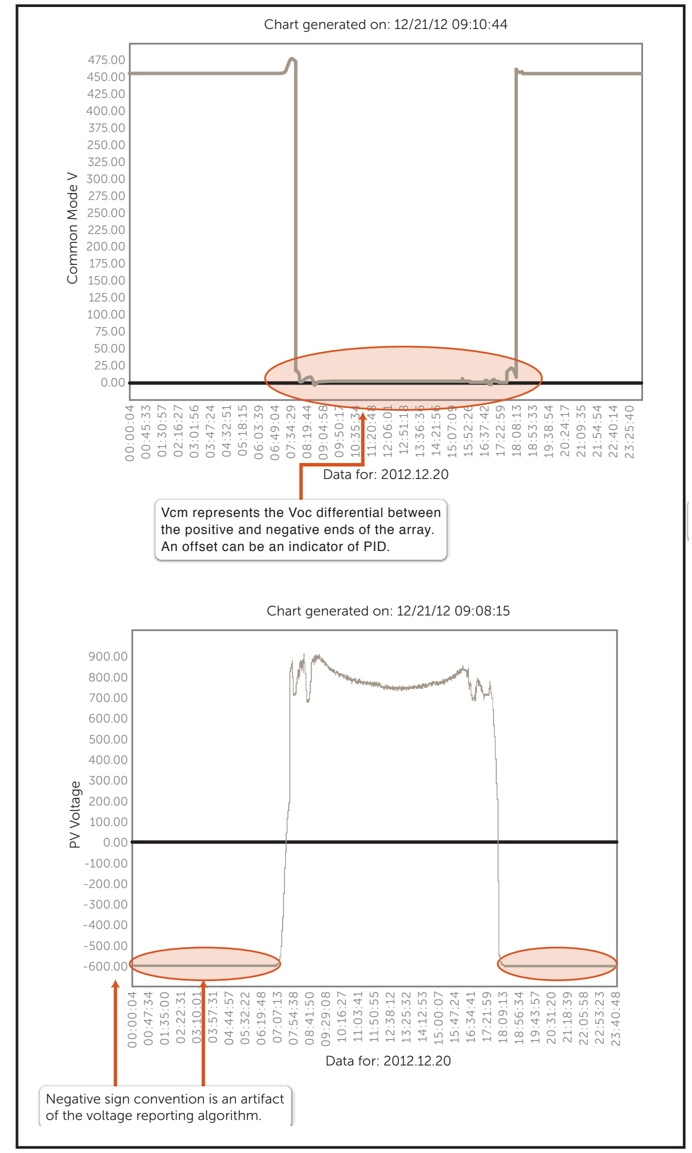

Figure 3 - The Equalizer on the AE 333NX inverter at this PV plant in southern California continues to keep V_{cm} under 25V on a daily basis (top graph). The Equalizer applies a +600V bias (bottm graph) on a nightly basis to reverse the effects of PID. (Note: The negative sign convention here is an artifact of the voltage reporting algorithm.)

While this example demonstrates the effectiveness of charge equalization at reversing the adverse effects of surface polarization, it is important to note that the occurrence of PID is rare. As of January 2013, Advanced Energy has shipped over 1.3 GW of model NX inverters, and the plant used in this example is the only one known to have required mitigation for PID, representing less than 0.1% of the installed base. In addition, a survey of major manufacturers of c-Si modules by Advanced Energy revealed that reports of PID remain quite rare. Nevertheless, other plants have installed the relatively inexpensive Equalizer kit as a preventative measure where the susceptibility of the modules to PID is unknown.

Conclusion

Potential Induced Degradation does not always occur, and mitigating PID is not always necessary. But because PID can have a significant adverse impact on a PV plant, it is of paramount importance for designers to understand the factors that cause PID, as well as the specific behaviors and effects of PID. Refer to the AE white paper *Understanding Potential Induced Degradation* for more information on causes and effects.

For modules susceptible to the Polarization Effect (reversible PID), the ability to maintain a PV plant's power performance cost-effectively with a charge equalizer circuit has been demonstrated. Advanced Energy's NX series of inverters allow for operation at a higher voltage inside the inverter and eliminate the need for an isolation transformer. Together these architectural advantages result in a lower levelized cost of electricity (LCOE).

Where a polarity restriction exists and PID is not reversible, Advanced Energy offers the TX series of inverters with an integral isolation transformer to create a grounded, monopolar system configuration. For c-Si panels the PID mechanism is usually reversible and "[f]or the described interaction between the panels and inverters it does not matter whether the inverter is equipped with a transformer or not." [1]

Advanced Energy remains committed to providing support for understanding and mitigating PID, and to work across the value chain to provide both short- and long-term solutions. The inverter options discussed here have been shown to work in certain situations, but should not be implemented without understanding the characteristics of the modules.

For additional information about Potential Induced Degradation or the mitigation options available from Advanced Energy, please contact AE Solar Energy's sales support team.

[1] Heribert Schmidt and Bruno Burger, *Interactions between Solar Panels and Inverters*, Fraunhofer-Institut für Solare Energiesysteme (ISE), December 2010

[2] S. Pingel, et al, *Potential Induced Degradation of Solar Cells and Panels*, 35TH IEEE PVSC, 2010