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Capabilities of the High Voltage Stress Test System at the Outdoor Test Facility

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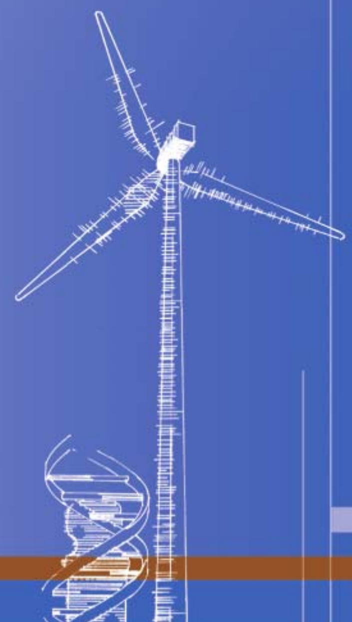

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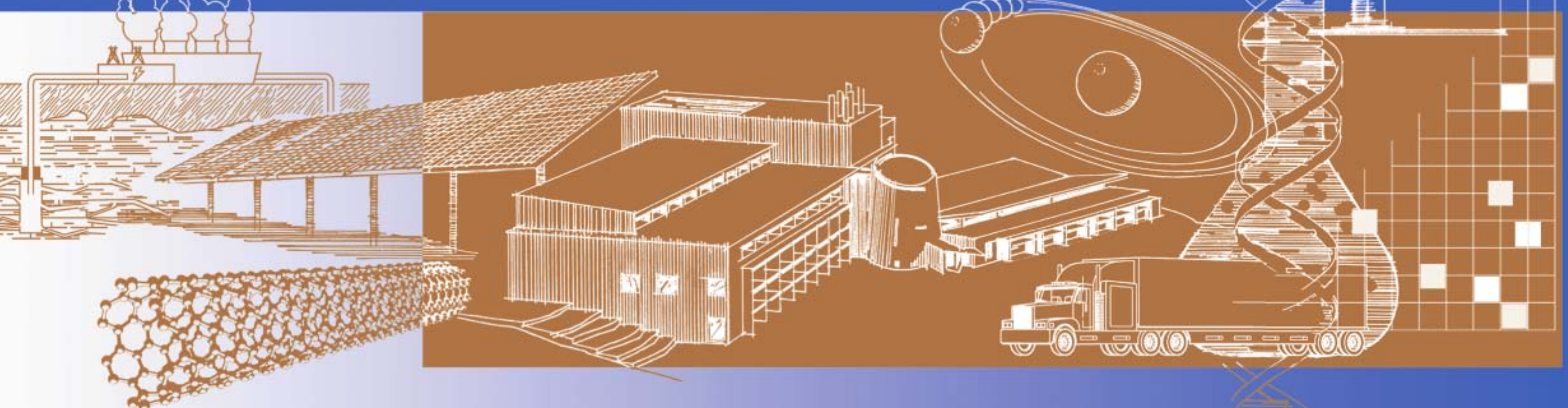

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ABSTRACT

We illustrate the capabilities of the High Voltage Stress Test (HVST) which operates continuously in the array field east of the Outdoor Test Facility at the National Renewable Energy Laboratory. Because we know that photovoltaic (PV) modules generating electrical power in both residential and utility-scale array installations will develop high-voltage biases approaching 600 VDC and 1,000 VDC, respectively, we expect such high voltages will result in current leakage between cells and ground, typically through the frames or mounts. We know that inevitably such leakage currents are capable of producing electrochemical corrosion that adversely impacts long-term module performance. With the HVST, we stress or operate PV modules under high-voltage bias, to characterize their leakage currents under all prevailing ambient conditions and assess performance changes emanating from high-voltage stress. We perform this test both on single modules and an active array.

1. Objectives

One long-term (2020) goal of the Solar Program Multi-Year Plan is to commercialize PV modules to have 30-year lifetimes or more, while sustaining less than 0.5% annual performance degradation rate, and at costs consistent with market-rates of electricity. In the 1980's, the Jet Propulsion Laboratory investigated the connection between leakage currents and contact corrosion in PV modules and established key thresholds of accumulated charge for crystalline-silicon (c-Si) and amorphous-silicon (a-Si) modules, ranging 1–10 coulombs per linear centimeter (C/cm) of module perimeter, and 0.1–1 C/cm, respectively, that would result in 50% failure in those modules [1]. We investigate the effects of long-term exposure to high voltage to assess whether current PV products can meet the Solar Program goals and to help identify potential product shortcomings and improvements.

2. Technical Approach

The purposes of the HVST are to stress PV modules to high voltage under long-term exposure at bias typical of their ratings, to monitor leakage currents between active PV cells and ground and correlate these against relevant ambient conditions, and to examine accumulated leakage charge against resultant electrochemical corrosion and impacts on performance. We study leakage currents produced under external high-voltage bias for single modules, or self-bias for arrays of modules, in both positive and negative voltage polarities. Leakage currents are monitored continuously using a data acquisition system (DAS), along with meteorological factors such as relative humidity, temperature, etc.

The HVST commenced phase I operations in 1998 using two c-Si and two a-Si modules, biased externally at ±600 VDC each. In 2002, we completed the analysis of the data taken on these modules and published the results from this phase I test [2]. We installed a second round of modules for the HVST late in 2001, and currently, we are into the phase II study of these modules that consist of two of each: c-Si modules, a-Si modules with frames, a-Si modules without frames, and polycrystalline (pc-Si) modules. All these phase II modules are biased at ±600 VDC externally. We anticipate analyzing the 4-year's worth of phase II data within the coming year.

During 2005, we installed a new high voltage array comprising 24 thin-film copper-indium-diselenide (CIS) modules deployed in two bipolar strings of nominally ±300 VDC open-circuit. This new array features a programmable multi-channel electronic load connected to the strings and interfaced to a DAS that executes full current-voltage (I-V) traces, peak-power tracking or other types of bias-profile (voltage, current) tracking continuously. Additionally, we monitor the leakage currents resulting from the array's self-bias from four separate groups of modules, two from each bipolar string, concurrently with the power and I-V data, which allows us to examine the connection between leakage currents and array operating conditions and how these are affected by meteorological conditions.

3. Results and Accomplishments

A principal outcome concluded from phase I was that the leakage currents (***i***) were thermally activated, strong functions of the ambient humidity, and quantifiable as formulated by Eq. 1, where RH, V_b, and T, respectively, represent the relative humidity, bias voltage and module temperature. On the right-hand side of Eq. 1, the pre-factor ($\boldsymbol{i_0}$) was found to be a function of temperature and bias, the activation energy E_A in the exponent was found to be a function of RH, and k_B is Boltzman's constant.

$$i(RH, V_b, T) = i_0(RH, V_b)\, e^{-E_A(RH)/k_B T} \qquad (1)$$

In phase I, we determined the dependence of i_0 and E_A against RH for the two module types and reproduce their behavior in Fig. 1. At high RH, the values of the E_A derived— ~0.9 eV (electron volts) and ~0.7 eV, respectively, for c-Si and a-Si modules—and sizes of leakage currents were consistent with conduction through the soda-lime top glass as being the predominant leakage path [2]. At low RH, the sizes of E_A—0.4 eV to 0.6 eV—and leakage currents were consistent with leakage paths along the EVA-glass interfaces as dominating the conductance.

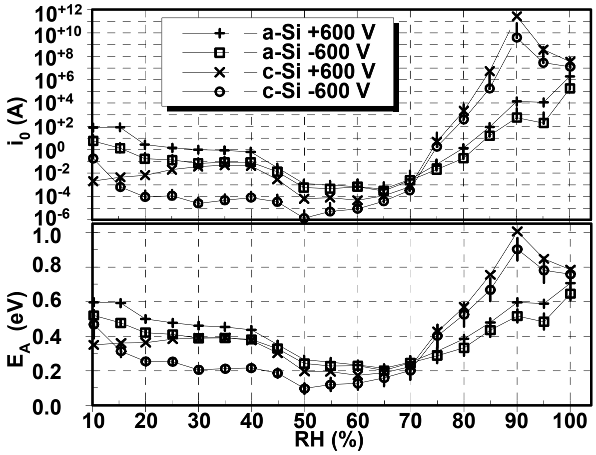

Fig. 1. Dependence of the leakage currents pre-factor i_0 and activation energy E_A, at top and bottom panes of the graph, respectively, plotted against relative humidity for two types of modules.

The new high-voltage CIGS array DAS allows us to scrutinize changes in performance by measuring the full I-V traces on a continuous schedule during daylight hours. This affords us the capability to distinguish performance changes that may result from separate changes in open-circuit voltage, short-circuit current, or fill factor for both string polarities, thus aiding identification of potential failures. Fig. 2 depicts sample I-V traces measured on April 13, 2005, which illustrate slight differences between the open-circuit voltages obtained from each string.

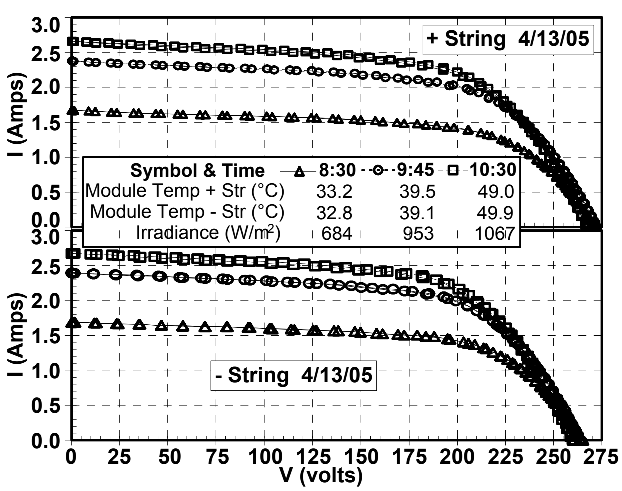

Fig. 2. Full I-V traces of new high-voltage CIGS array under various conditions, shown for (+) and (-) strings, respectively, at top and bottom panes.

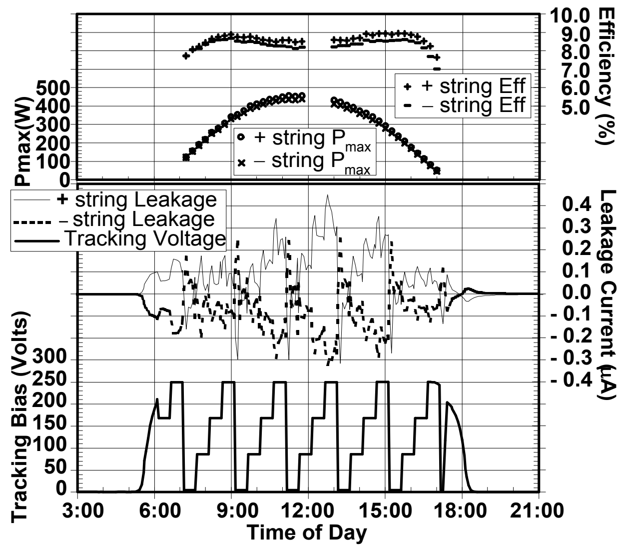

Fig. 3. Power and efficiency data read from left and right abscissa, respectively, in top pane, plus tracking bias and leakage currents, respectively, read from left and right abscissa, in bottom pane plotted vs. time of day for HVST CIGS array for both polarity +/- strings.

Figure 3 is a composite graph depicting multiple measurements performed with the new DAS and the new high-voltage CIGS array for September 26, 2005. At top and bottom panes, we show, respectively, the efficiency and power output and the effects of voltage-step time profiles on the leakage current from both polarity strings of the array. The tracking bias was stepped in discreet voltage jumps of 86 volts every 30 minutes. The resulting forcing effect on the leakage currents is visible and in-phase with the voltage steps, showing that at least on this day, the positive string leakage (~0.3–0.4 micro amps) appears larger than the negative. Concurrent efficiency and power data shown in the top part of the graph were obtained from I-V traces performed in 15-min intervals.

4. Conclusions

We quantify leakage currents and analyze leakage paths for PV modules subjected to long-term high voltage stress, deployed as single modules or arrays, thereby aiding early detection of potential corrosion problems in high-voltage PV power generation. For the HVST array, additionally, we can monitor long-term changes in performance concurrently with the leakage.

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