# PV Module Reliability and Durability Studies at the FSEC PV Materials Lab

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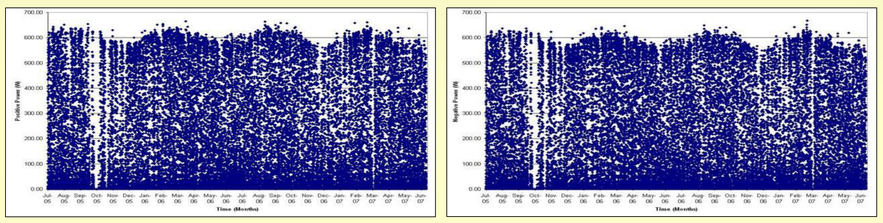
## *Introduction*

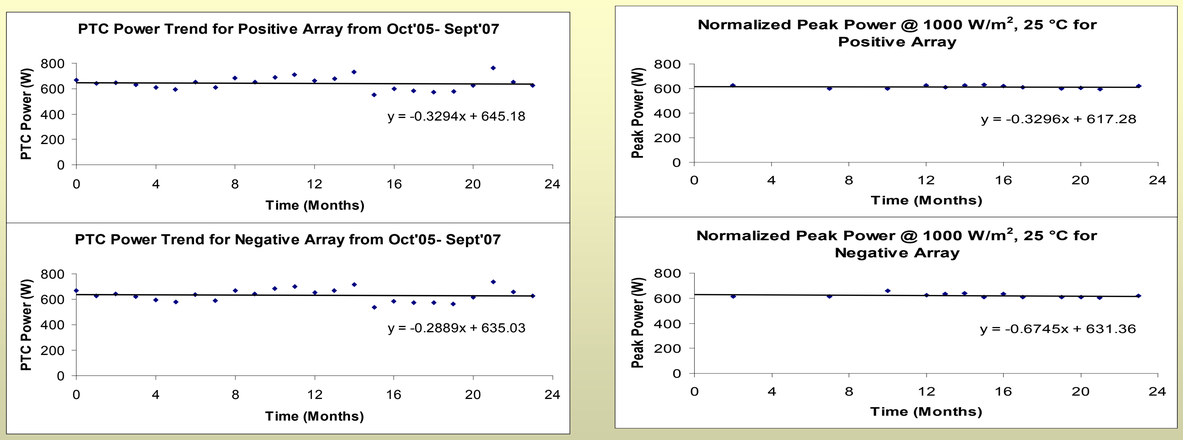
- Limitations of accelerated testing to predict all possible degradation modes and mechanisms for the PV modules necessitate actual outdoor monitoring and testing of PV modules to be carried out for extended period.
- Several parameters must be taken into consideration in order to characterize the performance of a PV device.
- These parameters include current and voltage generated by the PV device, solar irradiance, back of module temperature, relative humidity, wind speed, UV irradiance, and ambient temperature.
- It is essential to test PV modules under real time meteorological as well as electrical conditions and is advisable to carry out the testing in harsh climates such as the hot and humid climate of Florida and under high electrical stress conditions.

## *Outdoor Monitoring of PV Modules*

- PV modules are connected in two arrays that builds up to a maximum voltage of +600 V or -600 V. Each array is maintained near the maximum power point condition. Output parameters namely current, voltage, along with the meteorological parameters are monitored and recorded continuously using a data acquisition system (DAS).
- As the module array is maintained at near maximum power point condition the annual energy yield estimation can be carried out.
- The data collected over prolonged period can be analyzed using the PVUSA type regression and the annual degradation rates can be estimated.
- The periodic current-voltage measurements carried out on the arrays provides another approach for estimating the annual degradation rates. The two methods used for estimating the degradation rates complement each other.



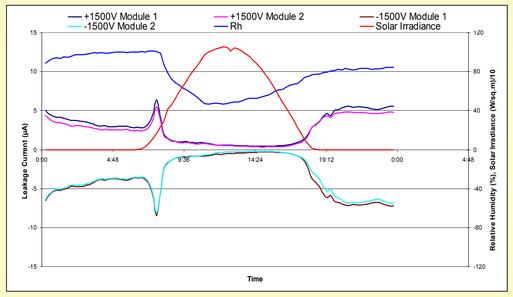

- Raw Data for positive and negative array
- Avg. annual energy yield estimated is 1385 kWhr/kWp/Yr.

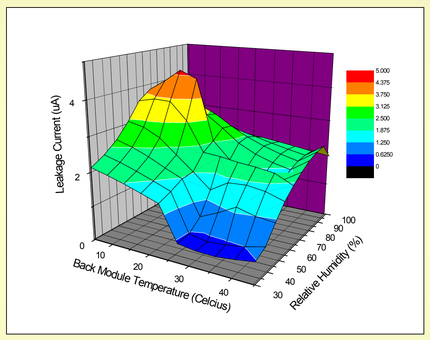



- The annual degradation rate calculated from the above graphs for positive and negative array is 0.6%/yr and 0.5 %/yr respectively with uncertainty of 1.5% using the PTC power trends over a two year period.

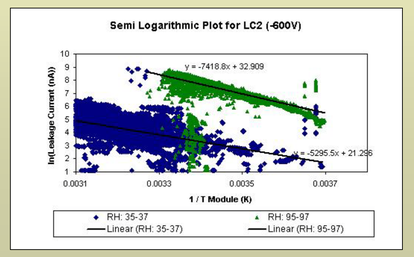
## *High Voltage Bias Testing of PV Modules*

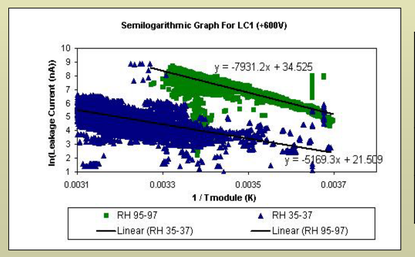
- In grid connected PV systems the PV cells may be at voltage as much as ±600 volts with respect to ground in USA and as high as ±1000 volts with respect to ground in Europe.
- Individual modules are generally biased from +150 V and -150 V up to +1500 V and -1500 V at the FSEC high voltage test bed.
- Such an outdoor high voltage bias test is more a realistic accelerated test as compared to damp heat test since it is exposed to solar irradiance, humidity and temperature cycling. PV modules are under bias even at night. Therefore, the high voltage bias testing acts as an accelerated test under near-real time conditions that the PV module would encounter in the field.
- The leakage current along with the relative humidity and ambient temperature is continuously recorded.



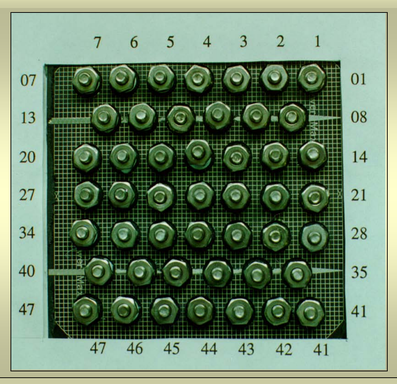

- It is essential to model the leakage current pathways in order to determine the possible degradation mechanisms. The photovoltaic module leakage conductance is thermally stimulated with a characteristic activation energy that depends on relative humidity that can be calculated by plotting the Arrhenius graphs.



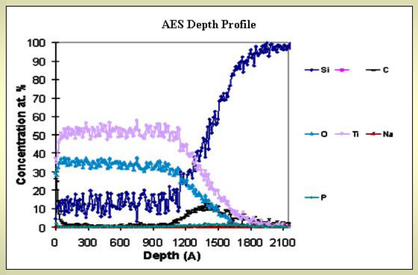



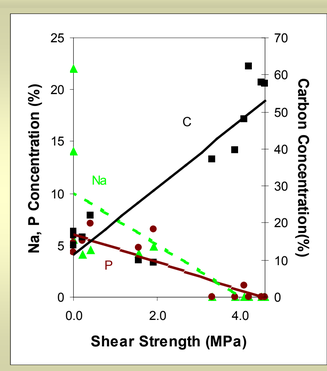

| Module Bias | Activation Energy (eV) | |
|---|---|---|
| | RH 35-37% | RH 95-97% |
| +600 V | 0.445 | 0.683 |
| -600 V | 0.456 | 0.639 |

## *PV Module Diagnostic Testing*




- Materials characterization and adhesional strength measurement is carried out after coring samples in PV modules. This destructive sample extraction process was developed at Sandia and further improved at FSEC.
- Adhesional strength can be measured in two ways- (1) Torque test (2) Peel test, however the torque test better simulates the actual shear type of stress conditions of the PV module.
- Chemical analysis of the extracted samples using techniques such as AES, XPS is carried out to determine the underlying cause behind an observed degradation and/ or loss in adhesional strength.




## *Conclusion*

- Over the years, FSEC has gathered wealth of data and experience in outdoor testing and high voltage bias testing of PV modules. Such study of PV modules of various technologies is essential to estimate the module lifetimes and for improving the fabrication technology.
- Annual degradation, seasonal variation and energy yield estimation are successfully determined for various PV Technologies.
- Over time, the sample extraction process has been modified and optimized with corresponding reduction in loss of samples. This enables to carry out adhesional strength testing as well as correlating the relationship between impurities migration and loss of adhesional strength.