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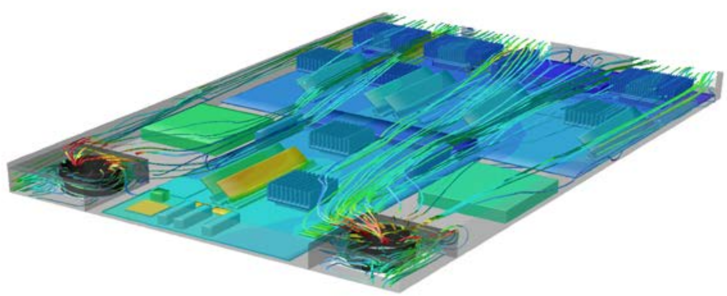

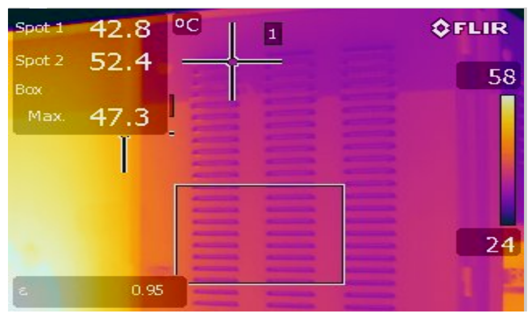

Photovoltaics Reliability & Thermal Phenomena

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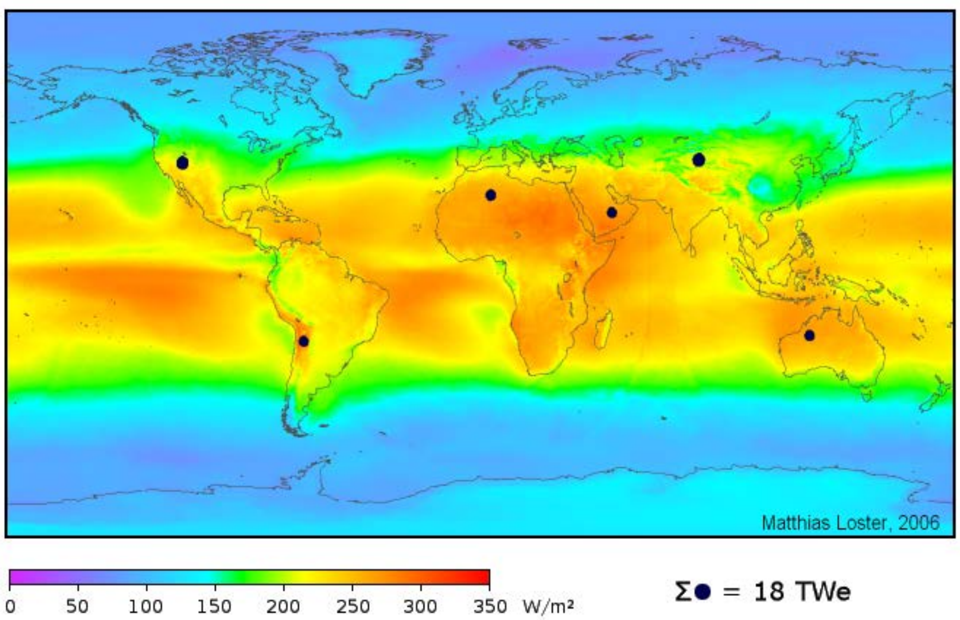
SAND Number: 2015-XXXXC

Solar Energy Potential

- Total Solar Constant (Earth) 1370 W/m^2
- Earth Albedo (Ability to Reflect Light): Ω = 0.37
- Thus, for the whole Earth, with a cross section of 127,400,000 km^2, the power is $1.74x10^{17}$W, ±3.5%
- 6 Boxes at 2.5 TWe each (2008 Worldwide Energy Consumption of $1.50x10^{13}$W – "Consumption by Fuel Statistical Review of World Energy" 2009, Energy Information Agency (EIA)
- Solar concentration to scale boxes

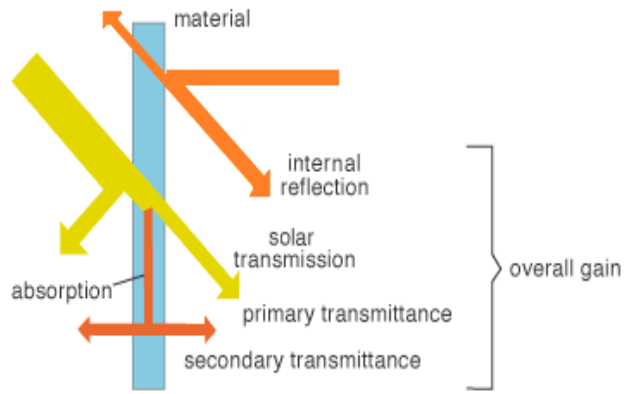


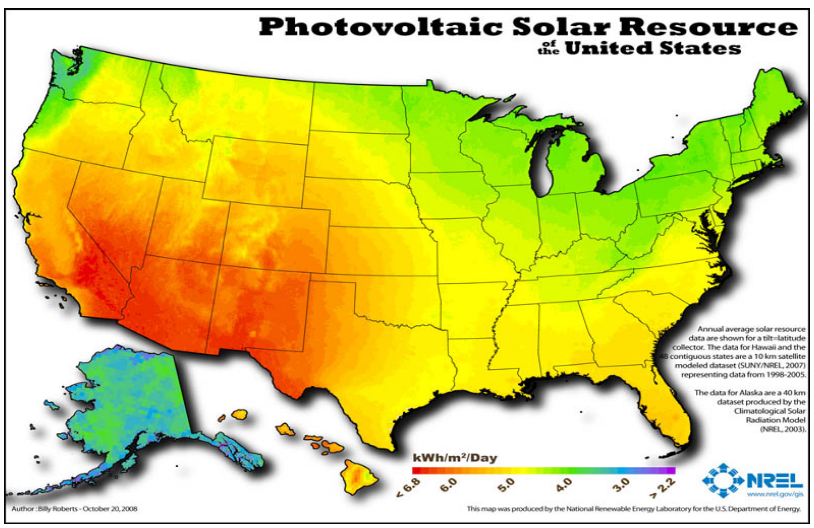
Issues of the PV Balance of Systems (BOS)

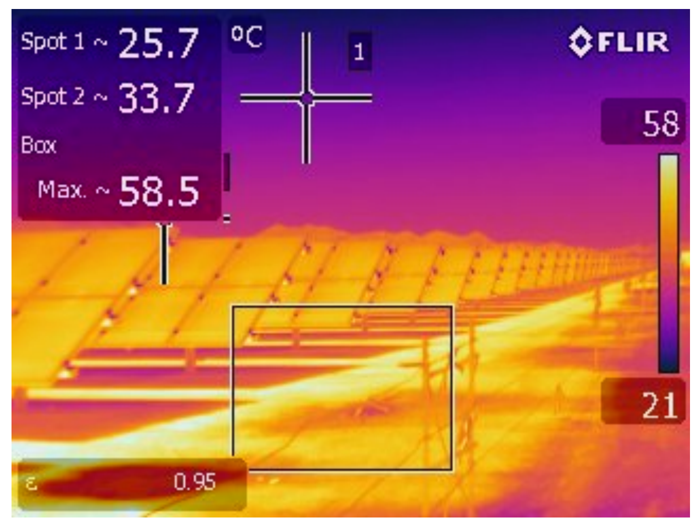
PV Reliability & Solar Thermal Gain

- Thermal gain from solar radiation in an object, space or structure, which increases with the strength of the sun, and with the ability of any intervening material to transmit or resist radiation.

Radiative Energy Balance:

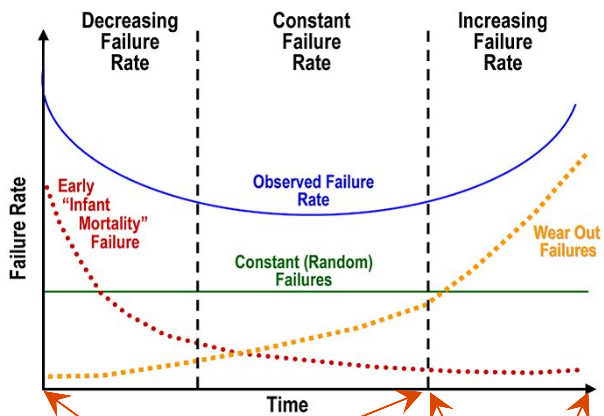






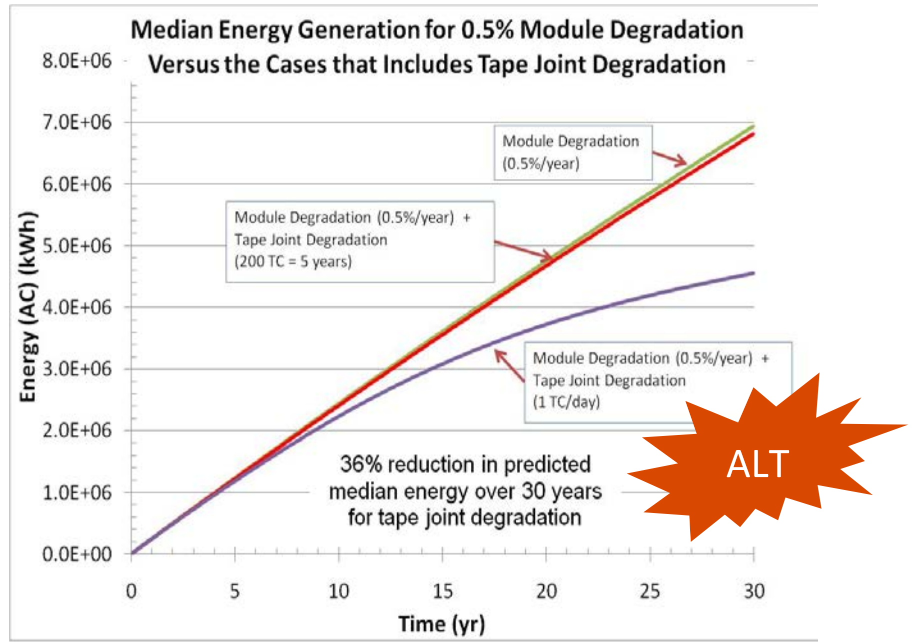
Laboratory testing provides vital information for PV system reliability

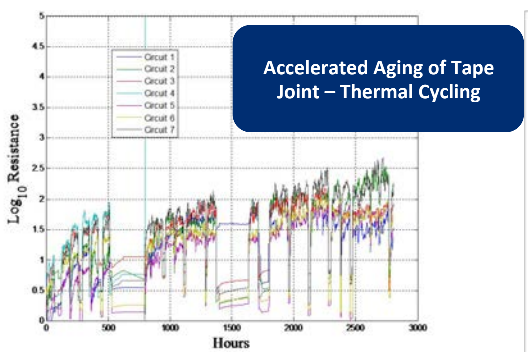
System performance model must include wear out (end of life) information

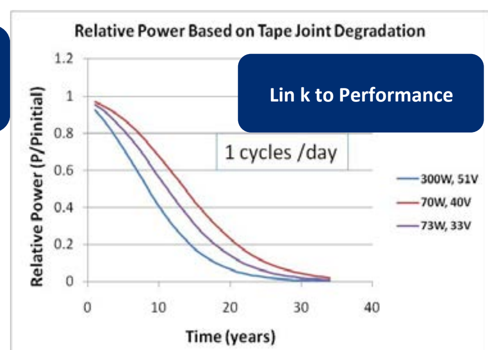


Field Data (O&M, Failures, etc.)

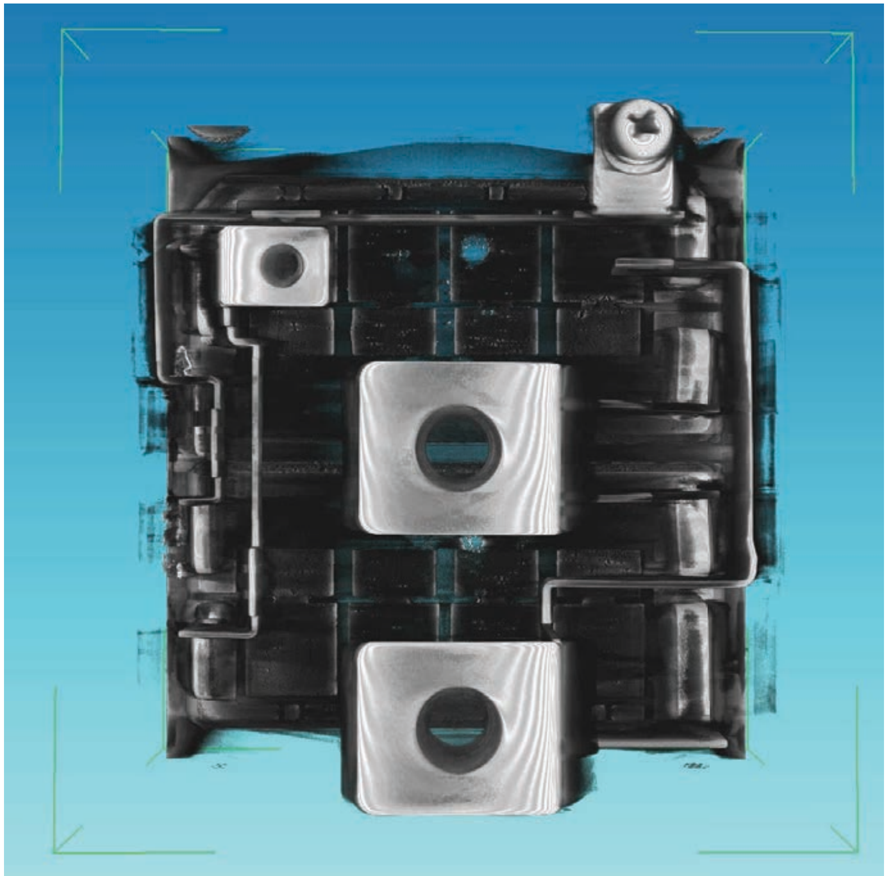
Accelerated Testing / Lab Tests

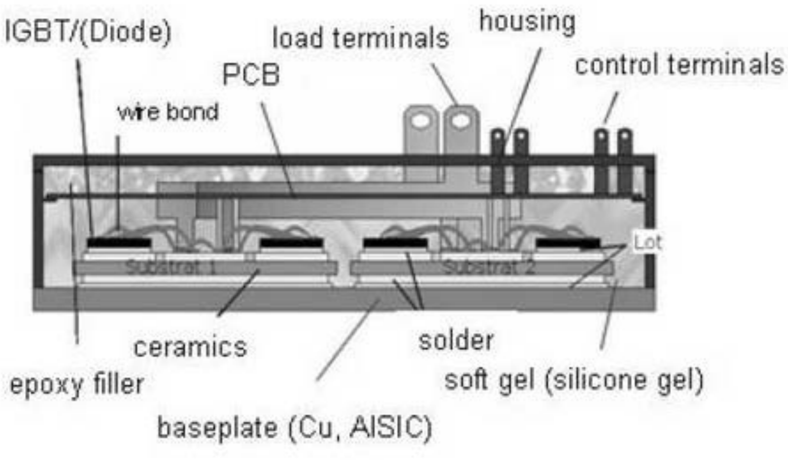






Acceleration Factors

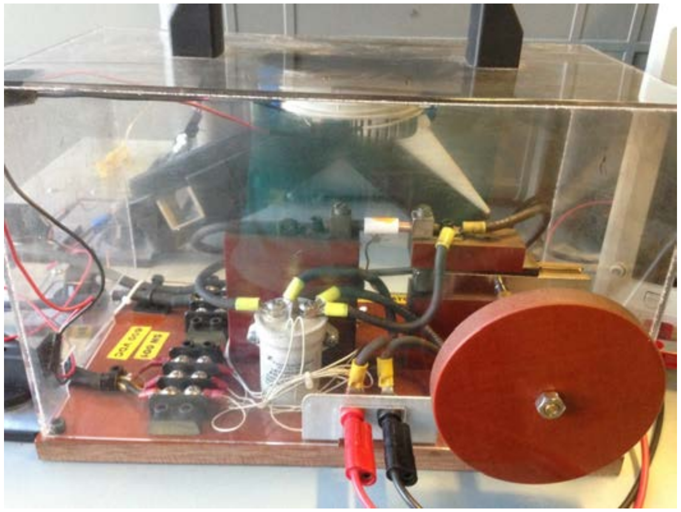


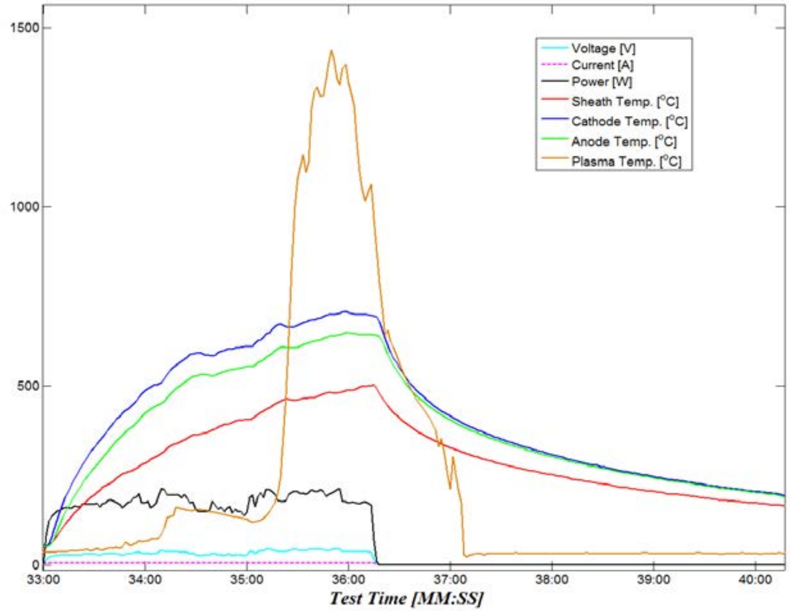


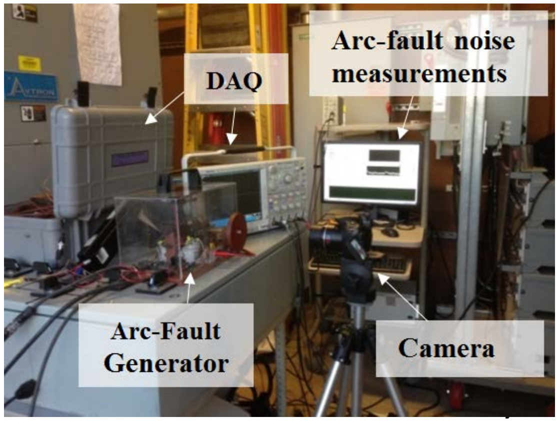
Construction of an IGBT module

DC-DC Plasma Arc-Fault Research

- Customized PV Simulator provided power to a developed Arc-Fault Generator.
  - A power resistor was employed to avoid shorting
- Dev. of NEC 690.11 & UL 1699B to define maximum AFCI trip times and safegaurds.
- Spectral Analysis to guard against nuisance tripping.







Arc Duration Trip Time

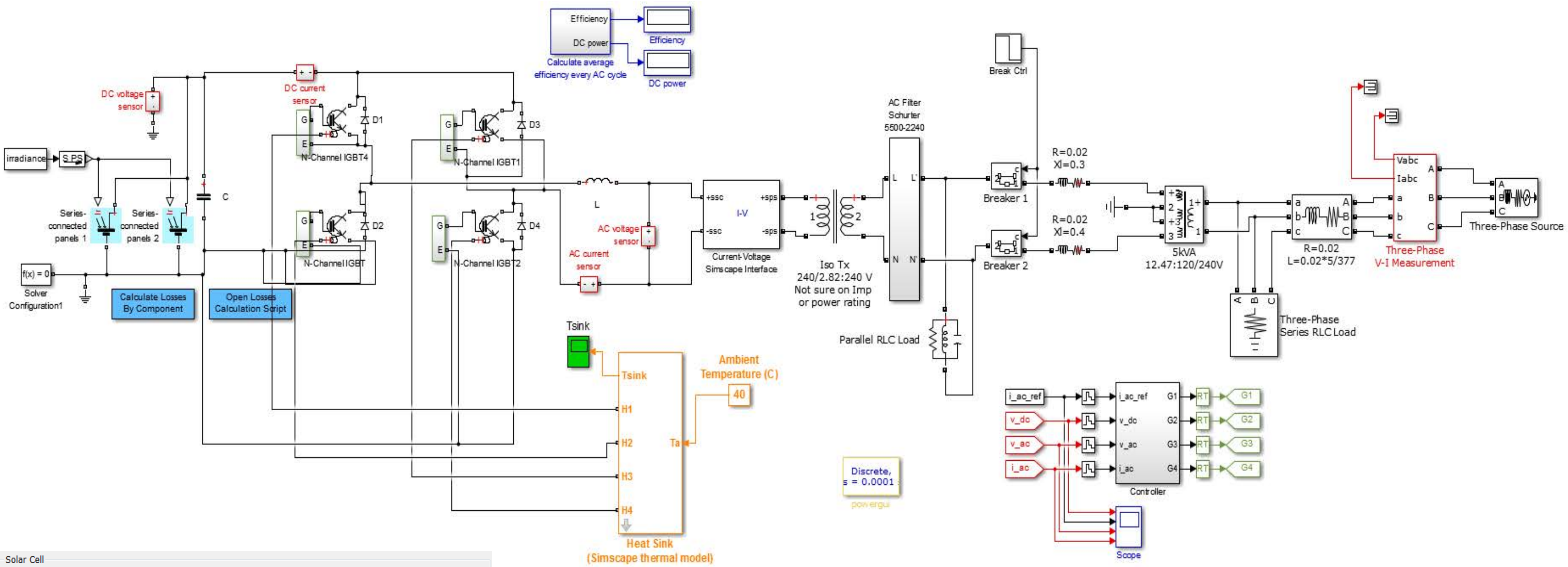
- Parametric transient temperatures determined for the (bulk) median radial temperature through the sheath.
- As the arc power increases there is less time before the polymer reaches the ignition temperature.
- Results suggest increasing arc-power levels can have impacts on ignition time scales, which requires rapid and accurate AFCI responses.
- UL 1699B defines the maximum AFCI trip time according to: $t_{trip} = min\left(2, \frac{750}{i_{arc} \cdot V_{arc}}\right)$

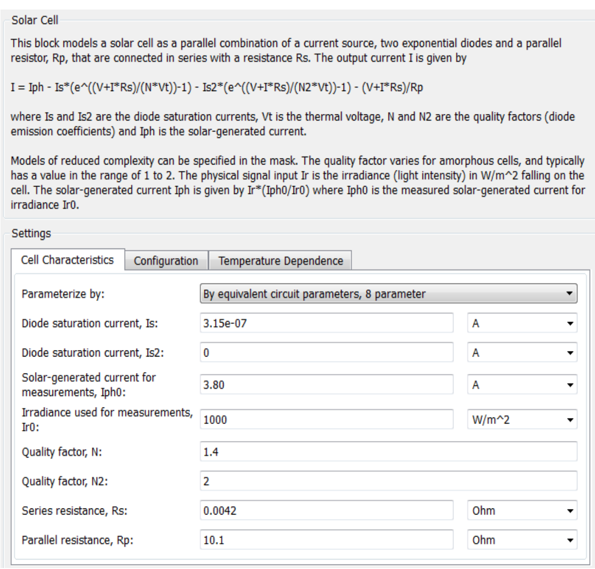
Arc Power [W]	Arc Duration Time [sec.] 0.20	0.40	0.63	0.83	1.15	1.50	2.00	4.00	6.00	8.00	10.00
100	25.79	27.03	33.06	41.94	61.23	86.90	128.03	297.40	425.27	499.96	538.53
300	25.91	28.87	40.87	58.66	98.42	153.16	242.46	556.19	694.35	743.50	760.65
500	26.05	30.78	49.15	76.87	140.46	229.68	372.76	754.14	861.42	890.81	898.93
650	26.13	32.00	54.49	88.81	168.60	280.93	455.90	846.23	936.74	958.79	964.23
900	26.27	33.99	63.38	108.97	216.57	367.08	584.86	961.27	1031.54	1046.20	1049.29
1200	26.44	36.37	74.23	133.93	276.20	470.04	719.73	1062.64	1116.78	1126.49	1128.25

Material Under Non-Destructive State
Material Undergoing Melting
Material Undergoing Fire Ignition

UL 1699B AFCI Maximum Trip Time
$T_{melt} = 155°C$
$T_{ignition} = 450°C$

SimElectronics Model





Solar Cell

This block models a solar cell as a parallel combination of a current source, two exponential diodes and a parallel resistor, Rp, that are connected in series with a resistance Rs. The output current I is given by

I = Iph - Is*(e^((V+I*Rs)/(N*Vt))-1) - Is2*(e^((V+I*Rs)/(N2*Vt))-1) - (V+I*Rs)/Rp

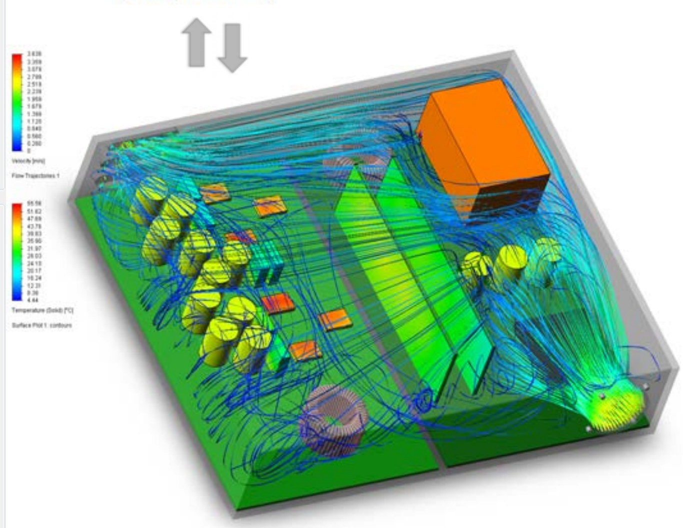
where Is and Is2 are the diode saturation currents, Vt is the thermal voltage, N and N2 are the quality factors (diode emission coefficients) and Iph is the solar-generated current.

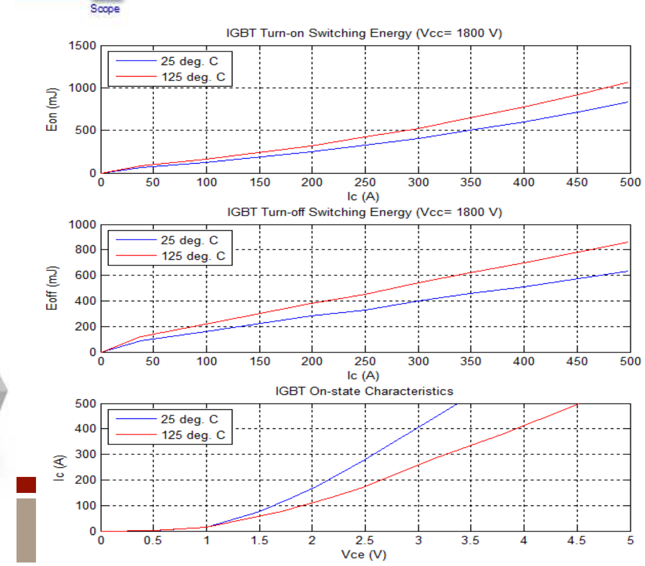
Models of reduced complexity can be specified in the mask. The quality factor varies for amorphous cells, and typically has a value in the range of 1 to 2. The physical signal input Ir is the irradiance (light intensity) in W/m^2 falling on the cell. The solar-generated current Iph is given by Ir*(Iph0/Ir0) where Iph0 is the measured solar-generated current for irradiance Ir0.

Settings

Cell Characteristics | Configuration | Temperature Dependence

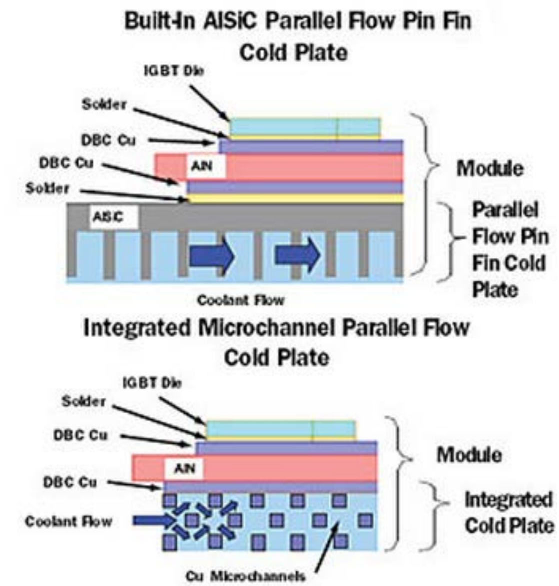
Parameterize by:	By equivalent circuit parameters, 8 parameter	
Diode saturation current, Is:	3.15e-07	A
Diode saturation current, Is2:	0	A
Solar-generated current for measurements, Iph0:	3.80	A
Irradiance used for measurements, Ir0:	1000	W/m^2
Quality factor, N:	1.4	
Quality factor, N2:	2	
Series resistance, Rs:	0.0042	Ohm
Parallel resistance, Rp:	10.1	Ohm

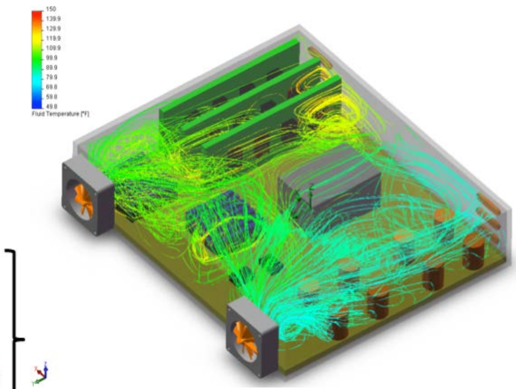


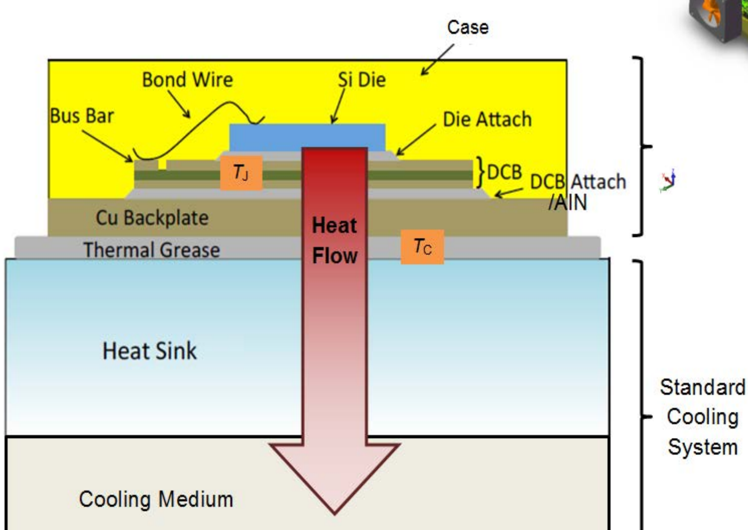


Power Electronics

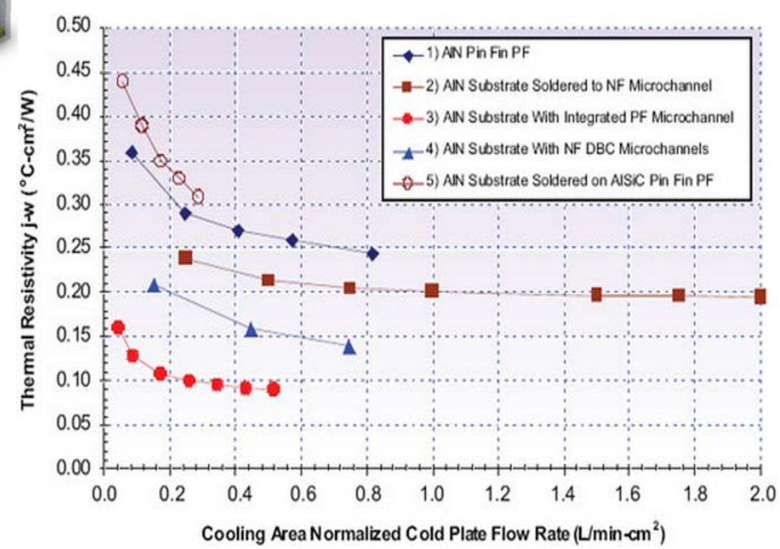
- Greater Number of Layers Increases R_{th} with Standard Configurations Capable of Thermal Dissipation Densities Up to 250-300 W/cm^2
- Power Cycling Degradation Impacts
  - Material Degradation and Micro-Fracturing
- CTE Mismatch Impacts







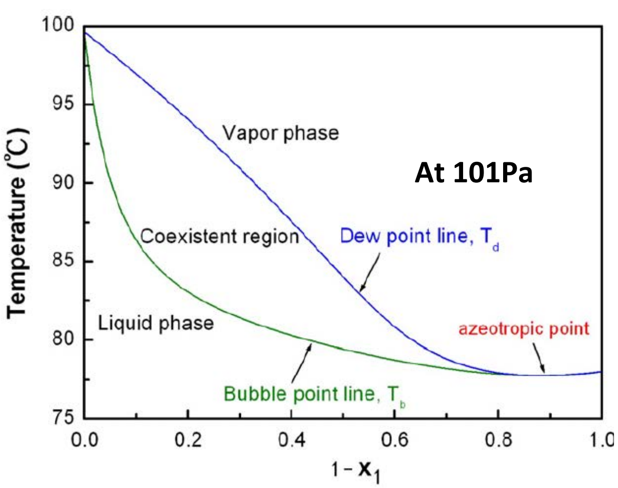
(Leslie et. al., 2013)

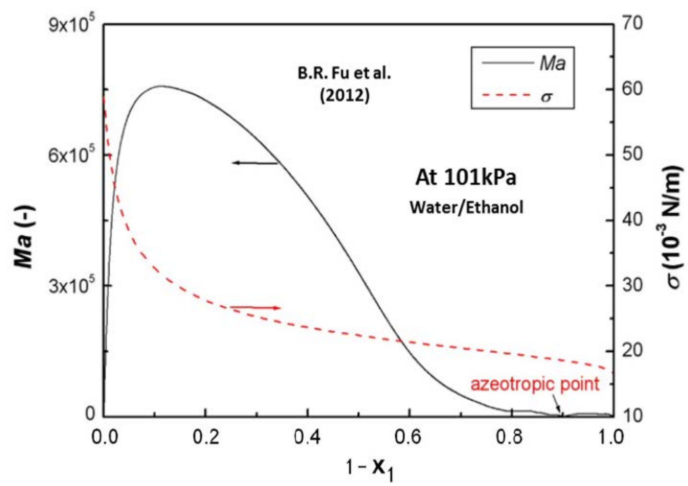


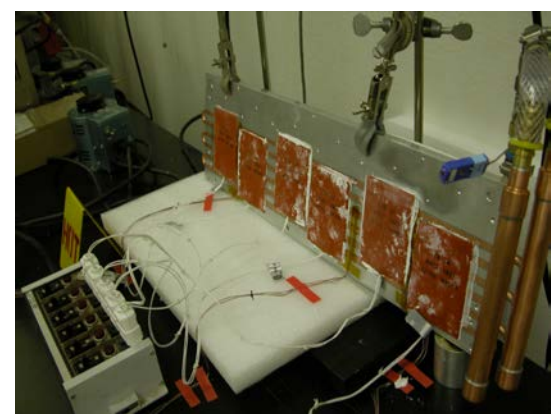
Heat Exchanger Cooling Plate

- Current Work Evaluating Heat Transfer Capability of Binary Mixture Working Fluids to Improve Heat Exchanger Performance
  - Propylene-Glycol (PPG)/Water
  - Ethanol/Water
  - Pure Components
- Alternative Adhesives Durability/ Performance Evaluation

[redacted]







Rifled Tubing vs. Smooth Tubing

- To improve the heat transfer rate from the heated wall to the flowing bulk fluid, rifled tubing designs have demonstrated increased turbulence.
- S.M. Bajorek and J. Schnelle (2002):
  - The increased internal surface area was found to improve the heat transfer coefficient as the convection effective area (Nu number) was greater than that of a smooth tube.
  - For an PPG/water, x_1=0.3 concentration an approximate 39% heat transfer coefficient improvement was observed using the Turbo Bill over a smooth pipe

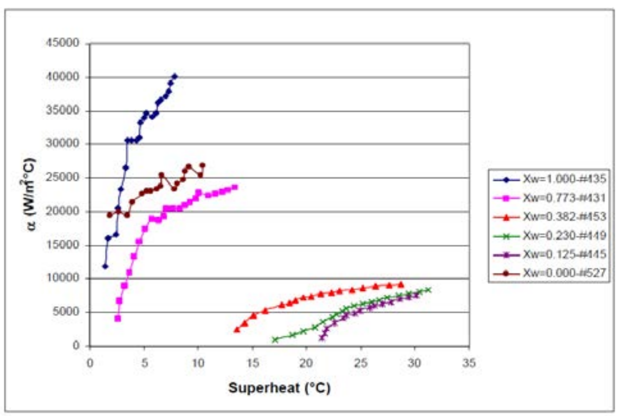


Figure 6.2-Heat transfer coefficient vs. superheat boiling curves for water/propylene glycol mixtures at saturation at 1.0 bar on the Turbo BIII tube.

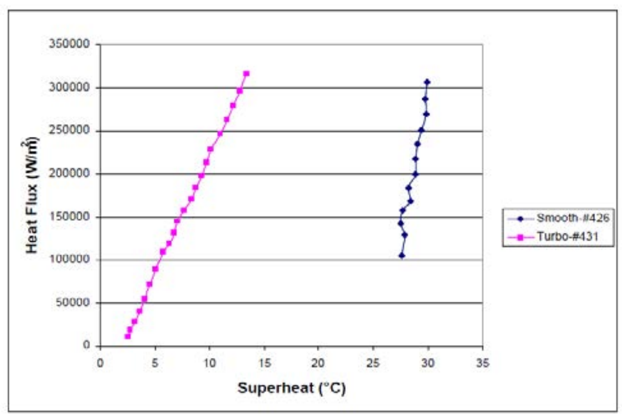
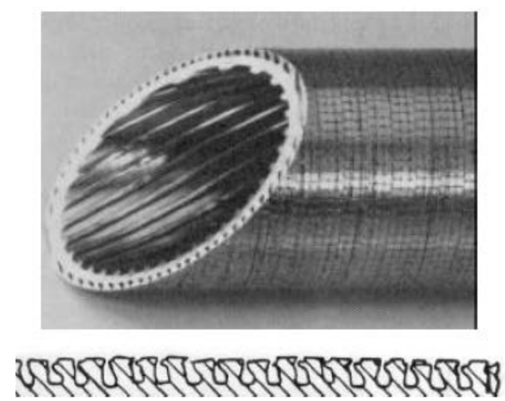


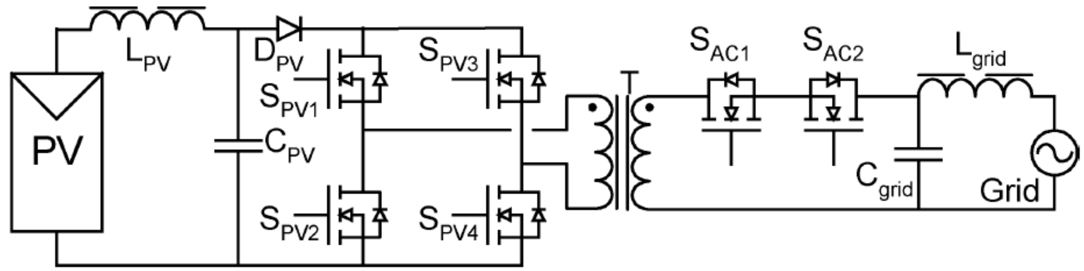
Figure 7.4-Boiling curve comparison between smooth and Turbo BIII tubes in X_w=0.773, X_{pg}=0.227 at saturation at 1.0 bar.

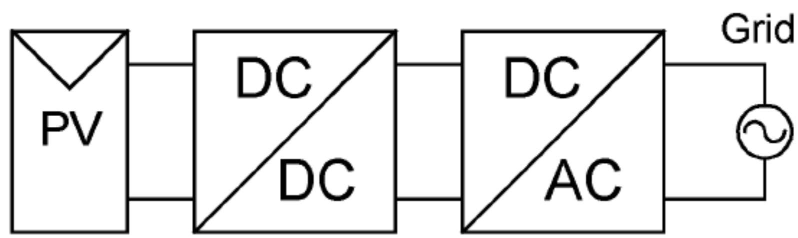


AC Module

- One PV module connected to a dc–ac inverter
- Very low voltage
- New converter concepts
- New advanced design concepts
- Improved performance and <u>reliability</u>.

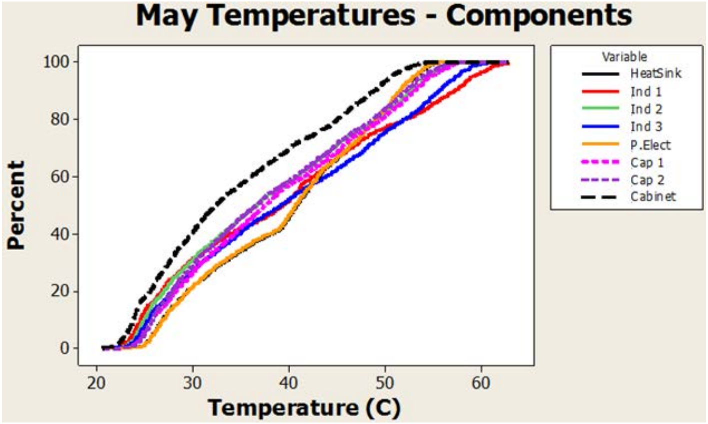
AC Module

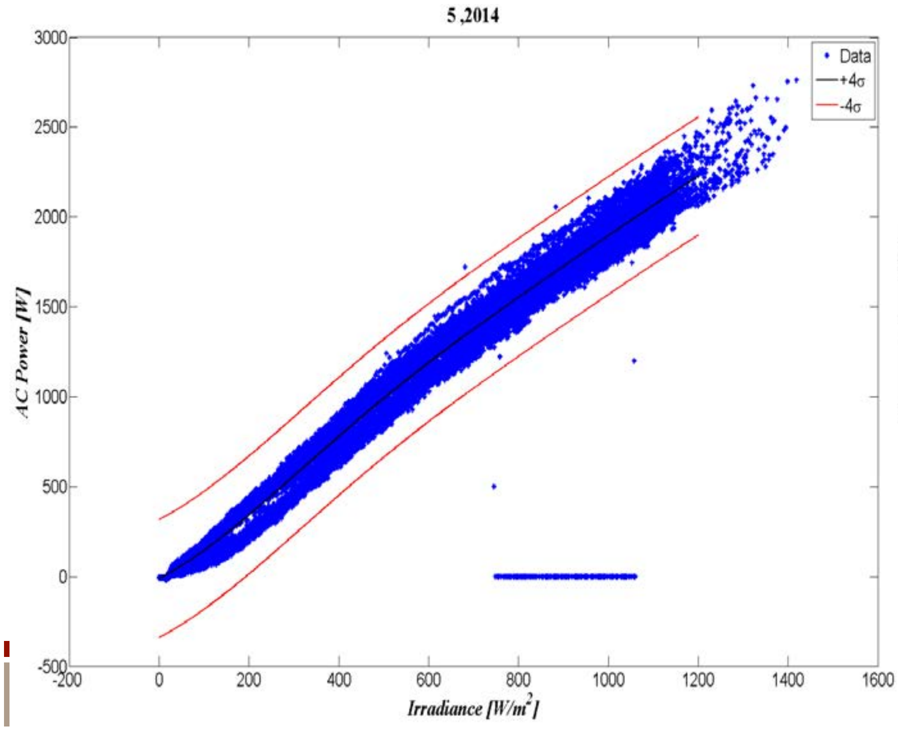


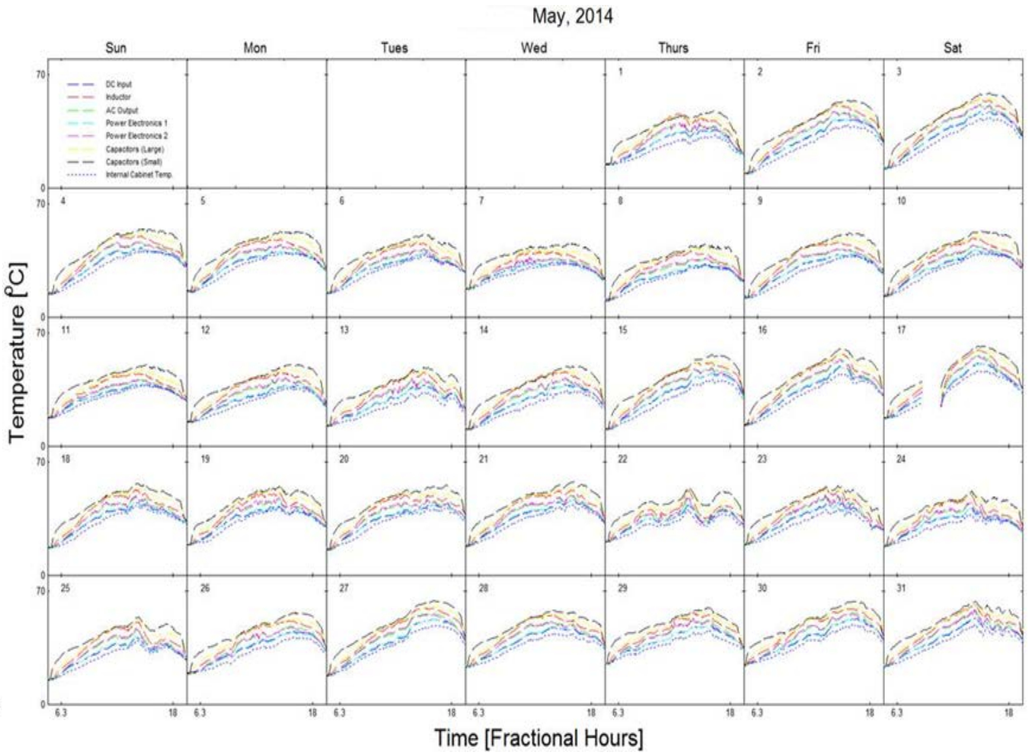


- AC module inverters are small interactive inverters that are supplied by a single PV module.

Fielded Studies Validation







The Solar Future

- Very Efficient PV Cells
- Roofing PV Systems
- PV Modules in High Building Structures

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Photons Affinities for Materials

- CPV solar cells are characterized by spectral sensitivities that trigger responses to natural changes in incident spectrum, which impacts cell performance as a fxn. of atmospheric conditions.
- Spectral effects result from differences between the actual (dynamically variable) solar spectrum incident on a solar cell in the field and the standard (fixed) solar spectrum used for rating purposes [Armijo, 2012].