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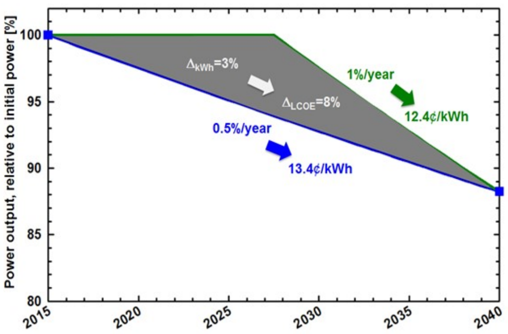

PV Lifetime Project – Challenges of Measuring PV Module Degradation

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Project Goals

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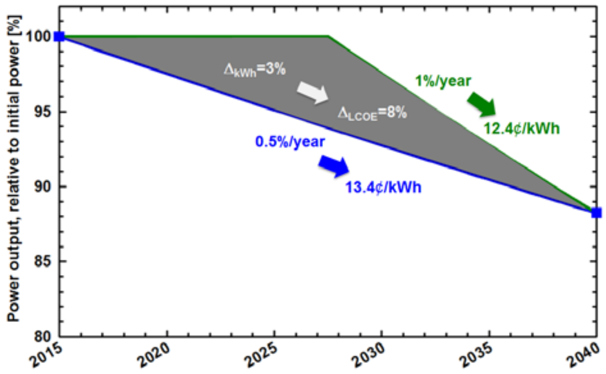
- Develop and standardize methods for measuring PV module and system degradation.
  - The path of degradation matters to LCOE.



- Apply methods to selected commercial PV modules
  - Three sites: New Mexico, Colorado, and Florida
  - Approximately 50 modules per climate (4 strings/system)
  - Modules obtained from at least two sources
  - Targeting top-selling module manufacturers (in US market) and a range of current cell technologies (focus on Si)
- Project is unique
  - Large number of modules will allow statistical characterization of variation in degradation within a module population – There is not a single rate!
  - Combination of indoor and outdoor methods applied a multiple sites as well as combining module-level with string-level monitoring.
  - Data and results will be shared

PV Lifetime Modules Under Test

Site	Manufacturer	Model	Technology	# of modules	Installation Date
NM	Trina Solar	TSM-PD05.08 260W	poly-Si	56	June 2016
NM	Jinko Solar	JKM260P-60 260 W	poly-Si	56	June 2016
NM	SolarWorld	SW 245W Mono	mono-Si	21	2013
NM	Canadian Solar	CS6K-270P 270W	poly-Si	48	October 2017
NM	Canadian Solar	CS6K-275M 275W	mono-Si	48	October 2017
NN	Hanwha Q-Cells	Q.Plus BFR-G4.1 280W	poly-Si PERC	48	October 2017
NM	Hanwha Q-Cells	Q.Peak BLK G4.1 290W	mono-Si PERC	48	October 2017
NM	Panasonic	N325SA16 325W	HIT Mono	48	TBD
NM	LG	LG320N1K-A5 320W LG NeON2	N-type Si	48	TBD
CO	Trina Solar	TSM-PD05.08 260W	poly-Si	56	September 2016
CO	Jinko Solar	JKM260P-60 260W & 265W	poly-Si	56	September 2016
CO	Hanwha Q-Cells	Q.Plus BFR-G4.1 280W	poly-Si PERC	28	October 2017
CO	Hanwha Q-Cells	Q.Peak BLK G4.1 290W	mono-Si PERC	28	October 2017
FL	Trina Solar	TSM-PD05.08 260W	poly-Si	56	September 2017
FL	Jinko Solar	JKM260P-60 260 W	poly-Si	56	September 2017
			Total	**701 Modules**	

PV Lifetime Systems (NM)

Trina (poly)

Jinko (poly)

SolarWorld/Enphase

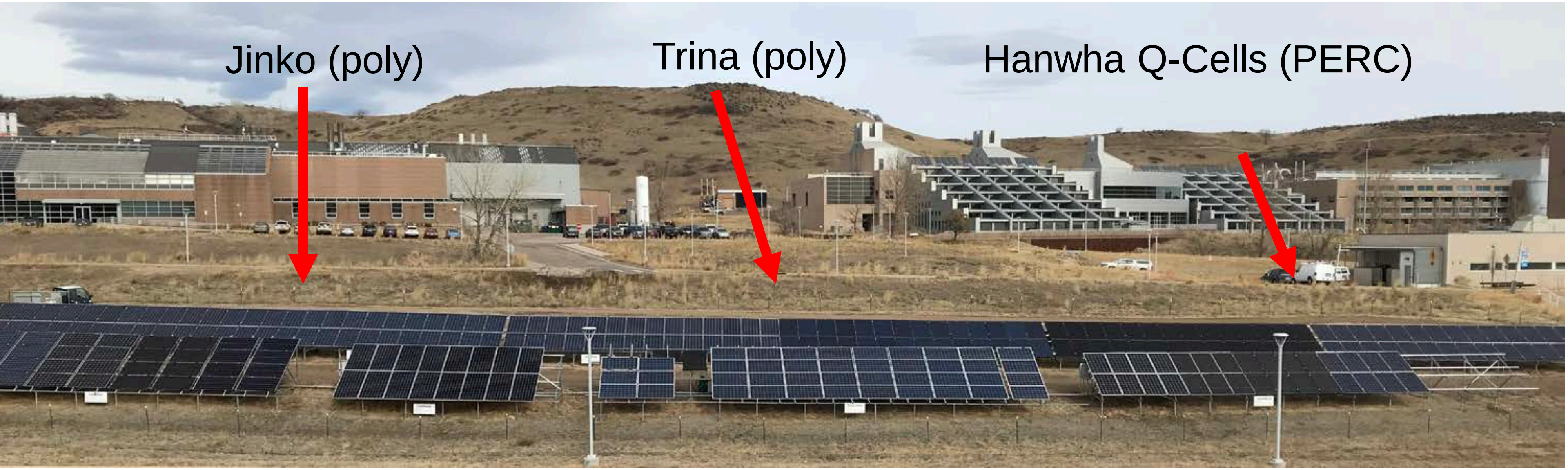
Hanwha Q-Cells (mono and poly PERT)

Canadian Solar (mono and poly)

PV Lifetime Systems (NREL)

Trina (poly)

Jinko (poly)



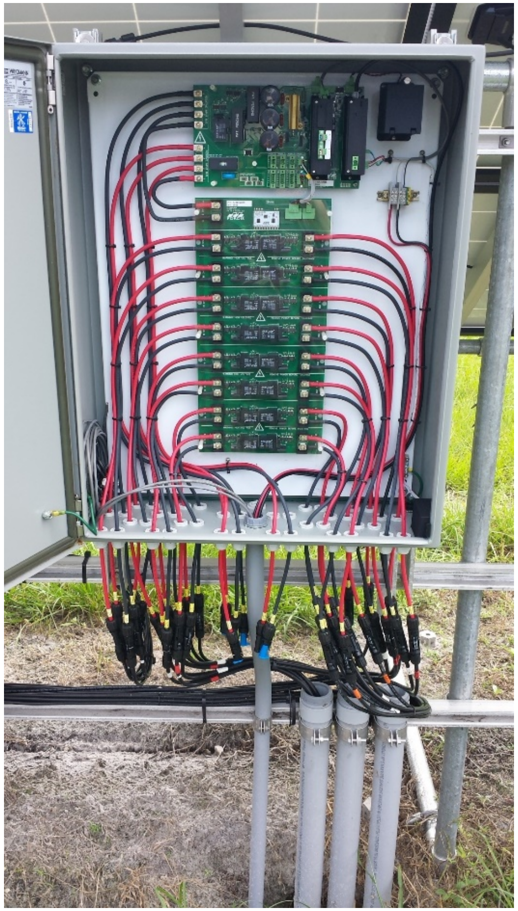
PV Lifetime Systems (Florida)

Trina and Jinko (poly)

Monitoring Data

- Indoor Flash Testing
  - All modules flash tested after initial stabilization from light soaking.
  - Annual reflashing of ~12 modules per system.
  - Flasher stability tracked with use of control modules stored indoors.
    - Control modules include samples matching the systems under test.
- Outdoor Performance Monitoring
  - Automatic string-level IV tracing (once every 30 min while irradiance is between 200-1400 W/m^2)
  - POA irradiance, back of module temperatures
  - 1-min, string-level dc current and voltage monitoring

Pordis 140A Series II
8-32 Channel IV Tracer



http://www.pordis.com/products.html

Flash Simulator Stability and Uncertainty

- Most focus is on accuracy of flash tests – Power rating = $$$$$$
- Our project is focused on measuring the *change in module performance over a long time period*.
- How stable are flash testers over time (years)?
- Current and voltage calibrations are straightforward.
- Irradiance calibrations are more difficult.
  - Flash lamps degrade leading to changes in spatial uniformity and spectrum.
  - Ref cells/modules used to calibrate flash intensity may degrade.
- **Our Proposed Solution:**
- Assume that a **collection** of stabilized PV modules stored indoors should remain stable for the project period.
- Collection is flashed periodically to track (and correct) changes that may occur.
- Collection helps to identify individual outliers to this assumption, which can be replaced.

- Will this work???

Sandia's Performance Monitoring Module Library

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- ~12 PV modules of different makes, models, and c-Si technologies.
- Flash tested regularly

Spec Sheet Temperature Coefficients

Manufacturer	Model	Alpha (%)	beta (%)	gamma (%)
BP Solar	BP3220N	0.065	-0.36	-0.5
Jinko Solar	JKM260P	0.06	-0.31	-0.41
Mitsubishi	PV-UE125MF5N	0.054	-0.343	-0.45
Moser Baer	MBPV CAAP	0.11	-0.344	-0.43
SolarWorld	SW 260 POLY	0.051	-0.31	-0.41
SolarWorld	SW 270 MONO	0.07	-0.29	-0.41
SolarWorld	SW 290 MONO	0.04	-0.31	-0.41
SunPower	SPR-318E-WHT-D	0.0565	-0.27	-0.38
Tenesol	TE235-60P+	0.0565	-0.3486	-0.43
Trina Solar	TSM260PD05.08	0.05	-0.32	-0.41
Universal Solar	WX230P-US	0.046	-0.3	-0.47
Yingli	YL220(156)	0.1	-0.37	-0.45

Sandia Spire 4600 SLP Stability Analysis

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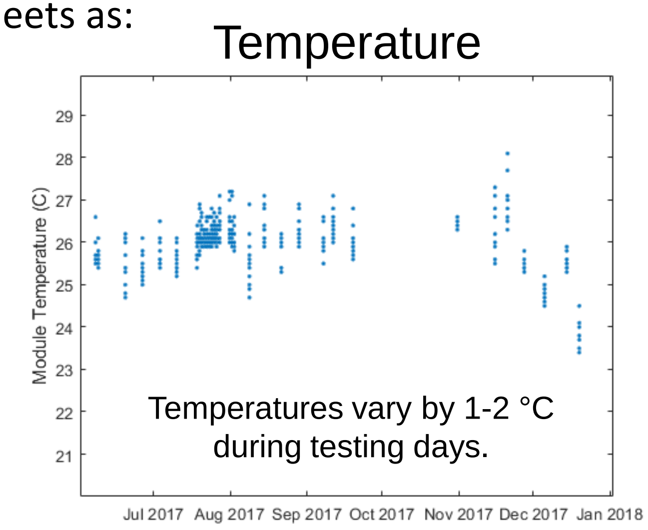
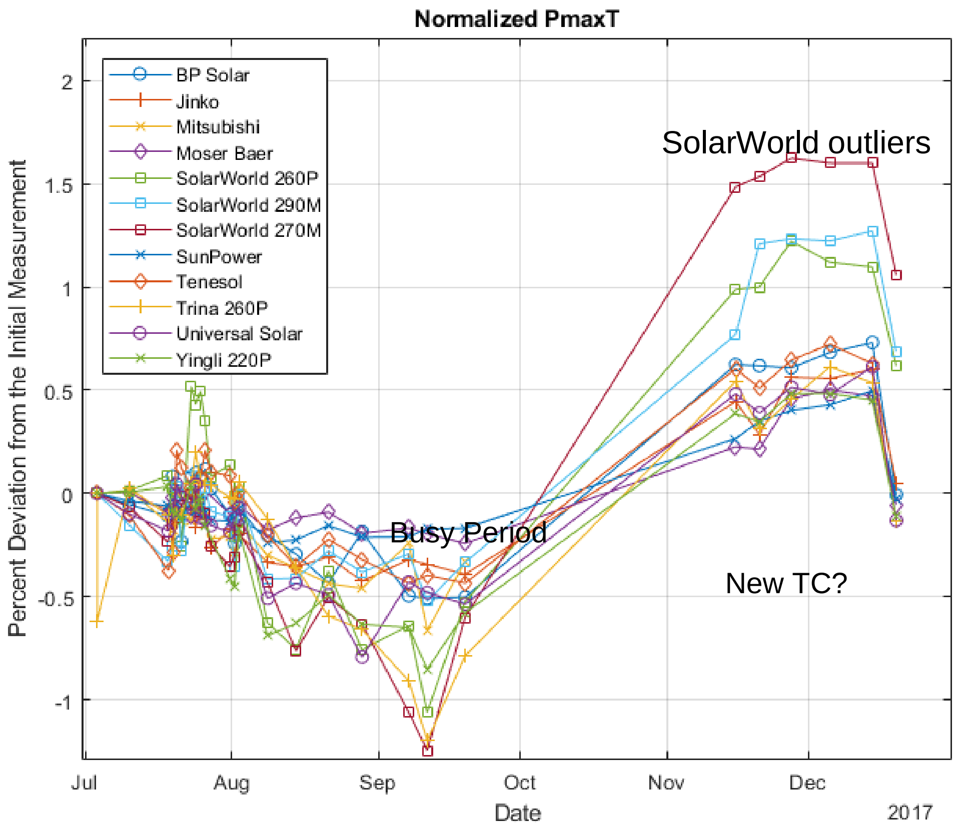
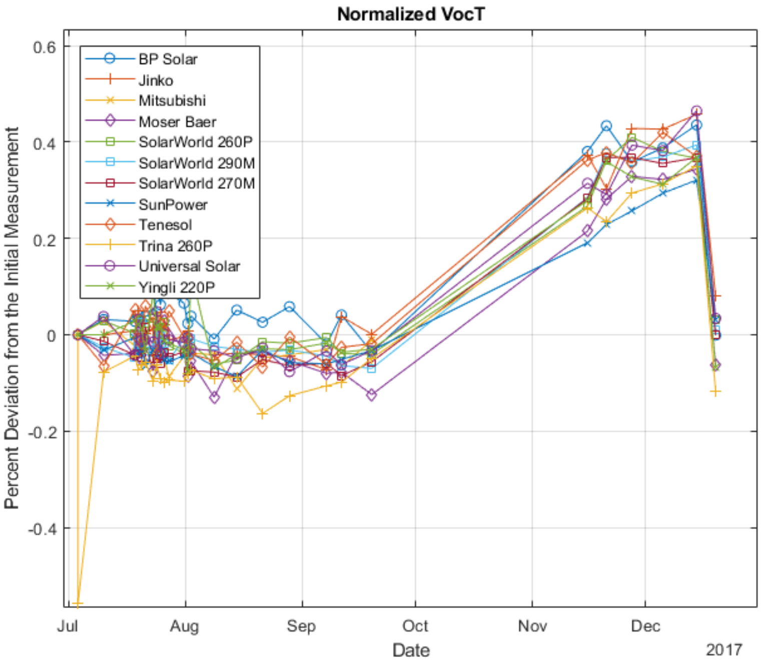
- Temperature correct Pmax using gamma values from spec sheets as:
  $PmaxT = Pmax / (1+(gamma_i /100) * (temp - 25))$
- Calculate normalized power residuals for each module as:
  $(PmaxT_t - PmaxT_1 / PmaxT_1 * 100$

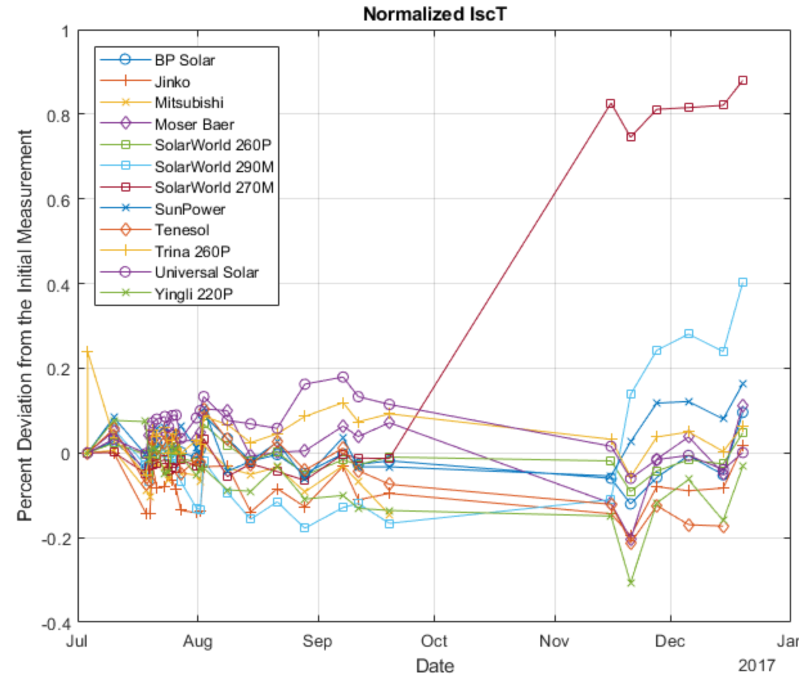


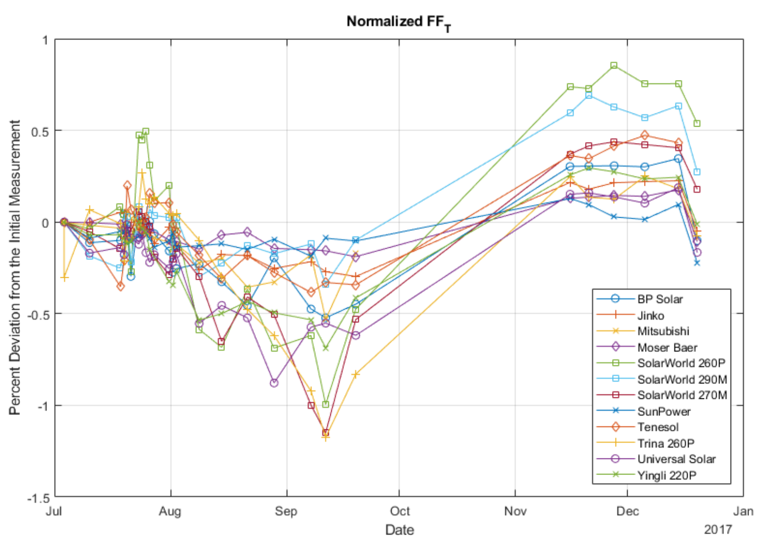


- Doors to lab were opened frequently during busy period in Sep.
- We believe that the TC was changed during this period. (We will record such changes in the future)

VocT, IscT, and FF

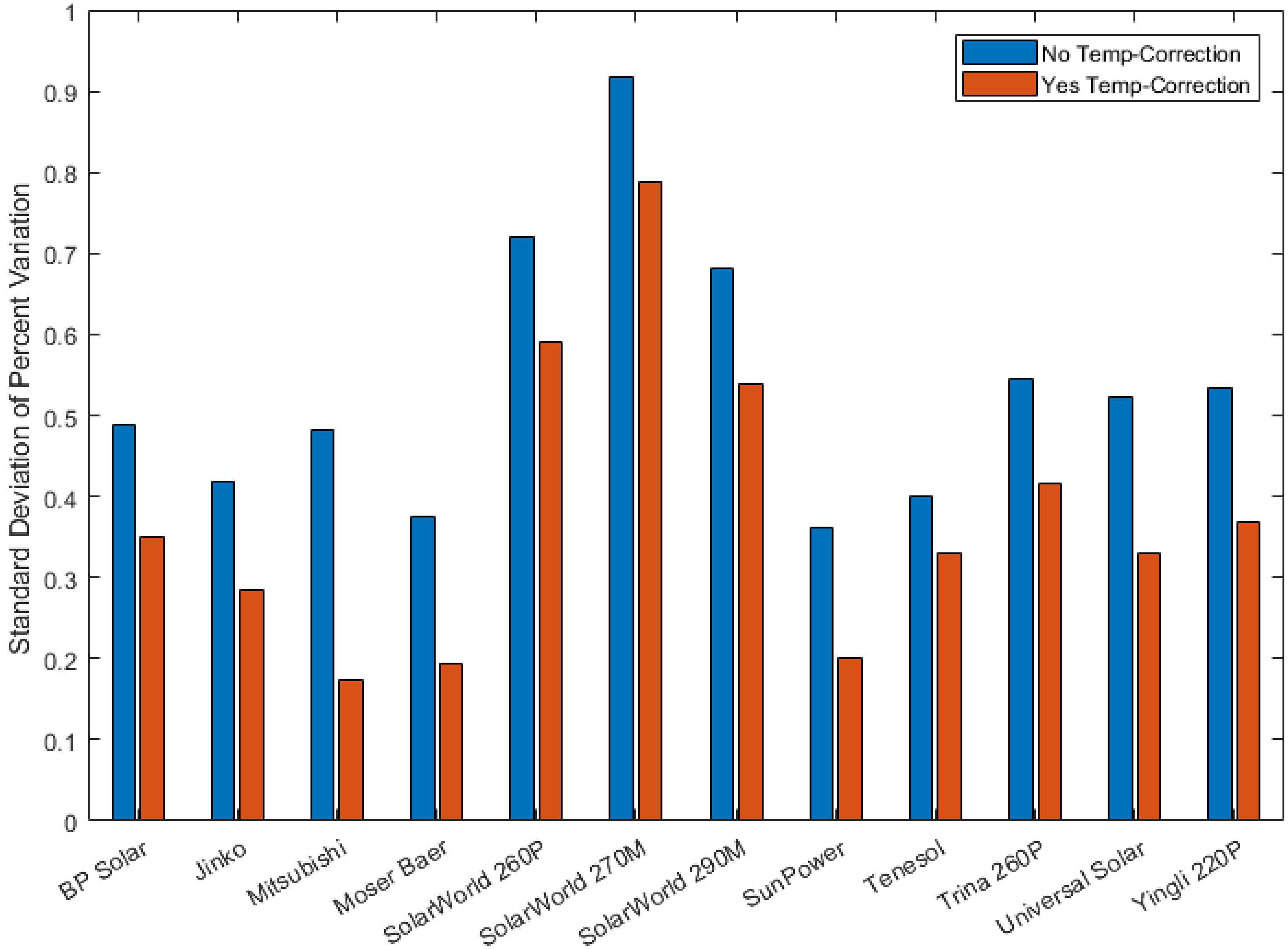


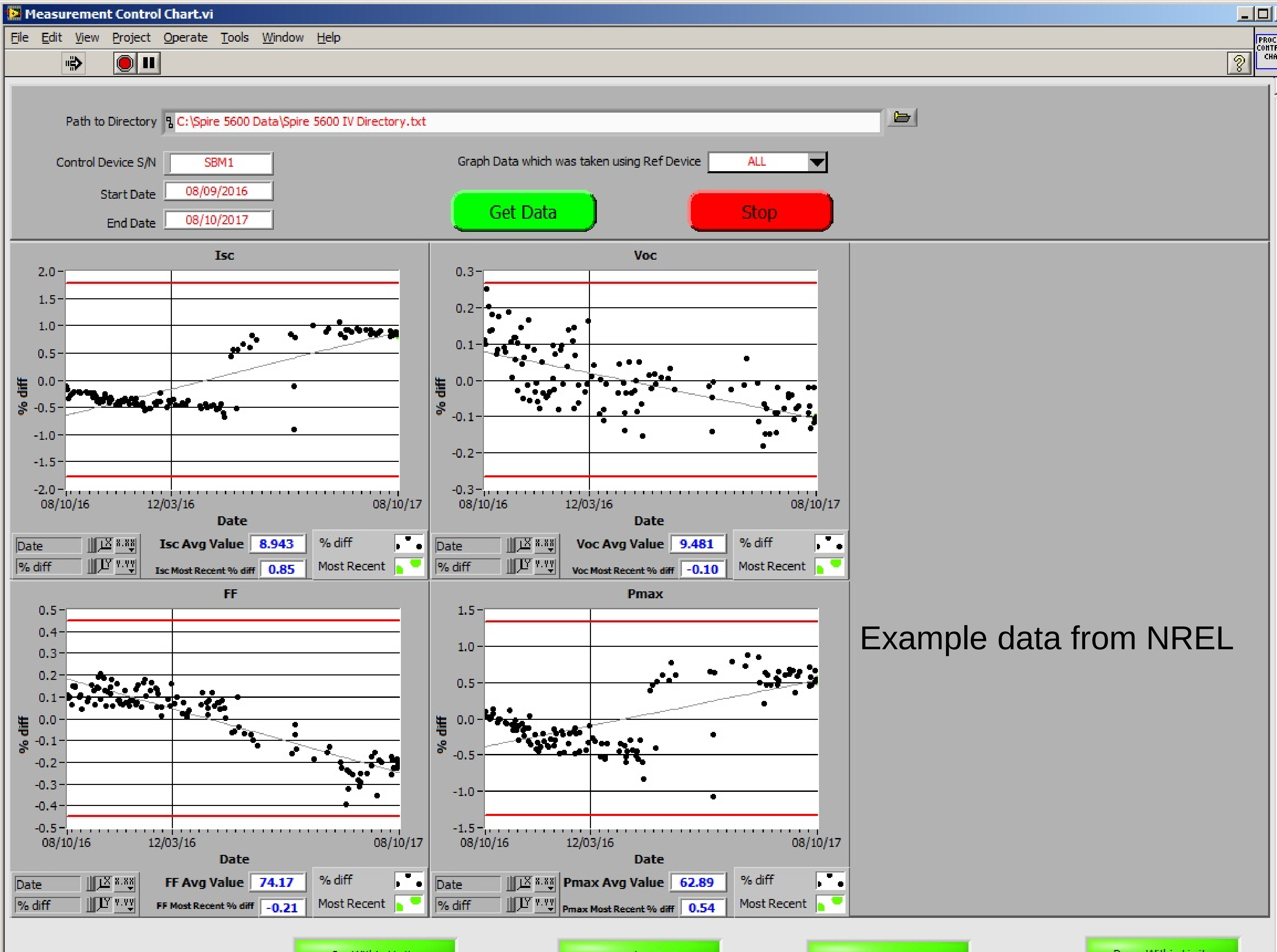




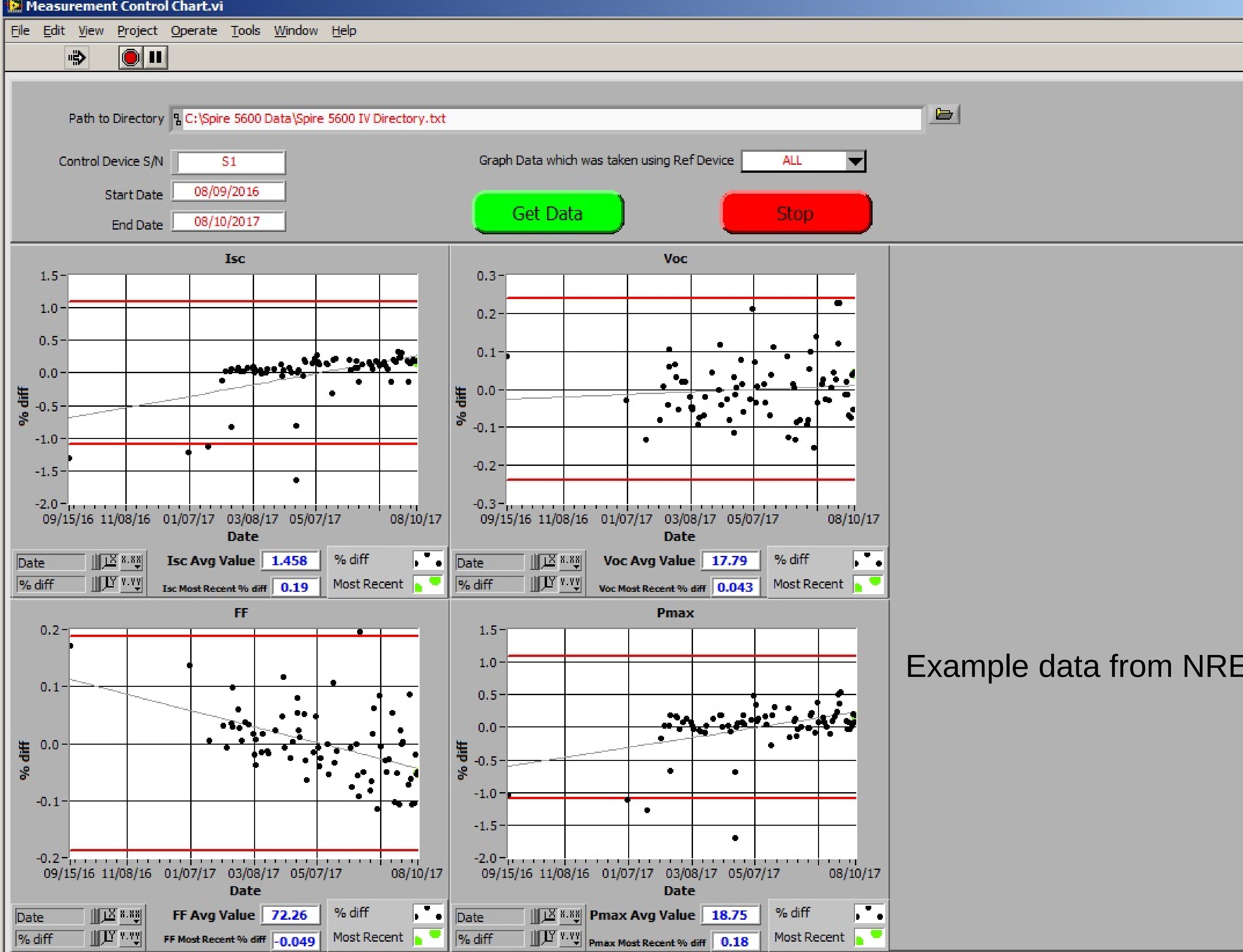
- ~0.4% increase in Voc between Sep and Nov, then return in mid Dec.
  - Could be a thermocouple being switched (~reading high by ~1+ degC)
- Isc values increase for SolarWorld 270M and 290M in this same interval. These modules are changing relative to the others in the library.
- Power changes tend to follow changes in FF

Temperature correction reduces variability





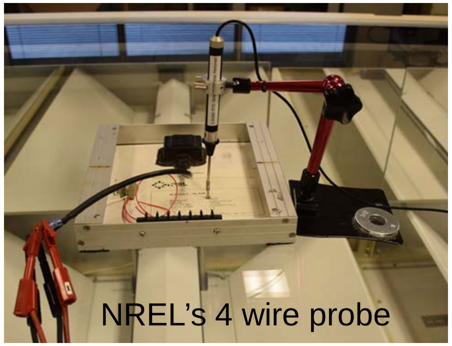
Example data from NREL



Example data from NRE

What Have We Learned?

- A collection of control modules appears to be justified since individual modules in our study started to deviate.
  - 2 deviated in Isc, one in FF – these will be replaced.
- Module temperature measurement
  - Taped-on thermocouple is not sufficient.
  - 4-wire RTD spring-loaded probe will increase our accuracy.
  - We will make several measurements across module to ensure uniformity.



- Errors of up to ± 1% appear to be the best we can currently expect.
  - This means that degradation rates of 1%/year or lower will take several years to measure with confidence. We are waiting to release results until confidence levels are better understood.
  - New temperature probe may reduce this uncertainty in the future.