Quantification of Risk of Unintended Islanding and Re-Assessment of Interconnection Requirements in High-Penetration of Customer-Sited Distributed PV Generation

Jovan Bebic, GE Energy Consulting

Final Project Report Webinar
July 22, 2015

Imagination at work

CSI RD&D
Program Manager

Overview

Background and motivation

The team and the technical approach

Quantifying the field conditions

Experimental setup and testing procedure

The results and the impact on PG&E interconnection process

Summary and the next steps

Background and Motivation

PG&E is the leading US utility in DG interconnections in terms of total number and total MW

- Over 2000MW of DG interconnected
- Added 600MW of DG capacity in 2014
- Receiving ~4000 applications per month and accelerating
- Implemented automated review of NEM applications
- Average of less than 5 days to interconnect NEM units

Islanding is a concern

- Safety and potential back-feed are major concerns
- Difficulty in getting actual islanding data due to large number of possible scenarios
- Lack of accurate inverter models (designs are proprietary)

Using inverters in a hardware in the loop configuration tests perceived as the best option to get more realistic data

What is islanding…

A condition when distributed generation is "on" and connected to the load but not to the bulk grid.

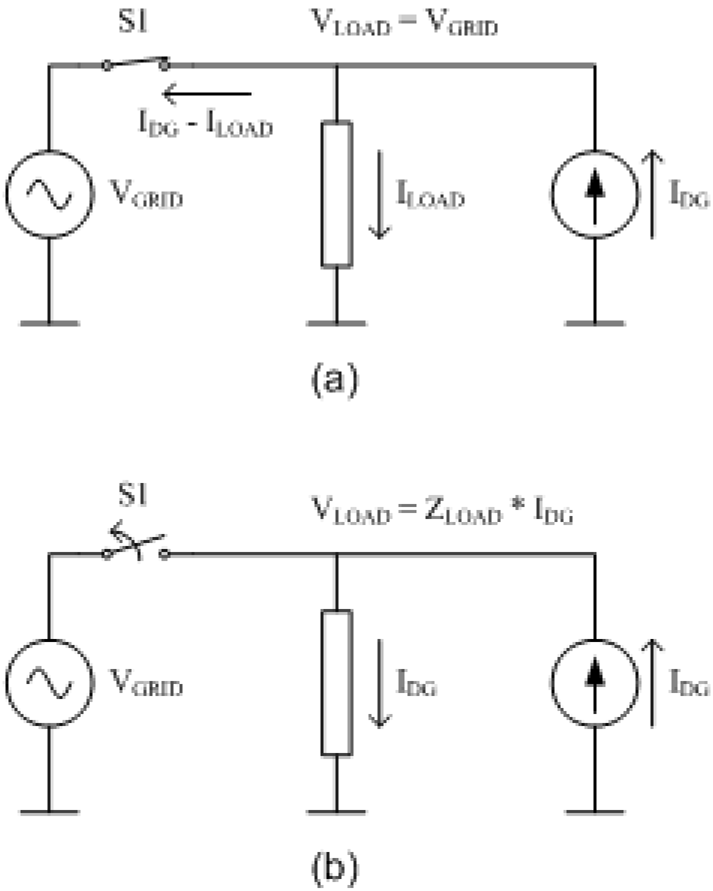
It arises after a switching action is taken to either clear a fault or reconfigure a circuit.

It must not persist – there is a safety risk to public and utility restoration crews.

UL1741 ensures that all certified inverters are able to detect an island condition and stop energizing the circuit.

UL1741 is based on a pass/fail single-unit type-test, it leaves a significant gray-area…

What are the Risks During Islanding…



During normal operation, a distribution circuit's voltage is defined by the power system.

Loads draw currents, PV inverters supply currents, but they both depend on the power system to define the voltage.

At the onset of islanding, the power system voltage is removed and the loads and PV inverters are left to themselves.

The electric transients between island formation and its eventual cessation are not well understood.

There is a potential of damage to the load, to the utility equipment, or to the inverters. These risks are curbed by the 15% rule…

The Team and the Technical Approach

Project Team

GO solar CALIFORNIA

Itron CSI RD&D Program Manager

- William Marin

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- Jovan Bebic
  Principal Investigator
  - GE Energy Consulting
    - Will Schmitt
  - GE Global Research
    - Maozhong Gong
      Pat Hart
  - PG&E Distribution
    - Chase Sun
    - Tom Huynh
      Phuoc Tran
  - PG&E ATS
    - Al Beliso
      Adam Eberwein
    - Dan Kaufman
      John Mead
      Manny D'Albora

Owen Schelenz
Tony Galbraith
John Harrison

Technical Approach

Quantify Field Conditions

- Spatial correlations between load types and PV
- Temporal matching of load and PV
- Load modeling based on WECC guidelines
- Define priority sequence for testing

Design the Experiment

- Design and commission the amplifier
- Design and commission the measurement system
- Characterize performance
- Streamline test procedure

Test and Analyze Data

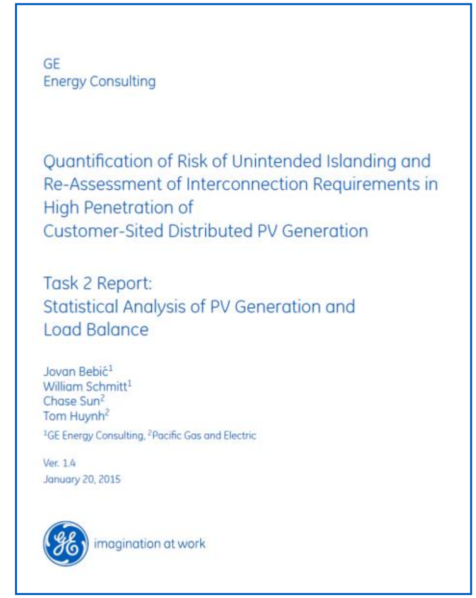
- Screen test results for acceptance
- Signal processing to extract P, Q, f, RMS values, sequence components
- Quantify attributes: duration, max V, max V imbalance…

Evaluate Impact on Interconnection

- Group, pivot, visualize… to understand relationships
- Propose changes to interconnection rules & scope field validation
- Champion to PG&E technical stakeholders
- Disseminate to utility industry

Quantifying the Field Conditions

Analysis Approach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Task 2 Report:
Statistical Analysis of PV Generation and Load Balance

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Ver. 1.4
January 20, 2015

imagination at work

Spatial correlations

Tile the load zone with uniform squares

Aggregate load by type
- Industrial
- Commercial
- Agricultural
- Residential

Aggregate PV

Compare

Topological processing

Analyze circuit topologies to identify sections

Aggregate load in each section by type

Temporal conversion

Transform to temporal profiles using PG&E conversion factors

Transform to composite load models using WECC guidelines

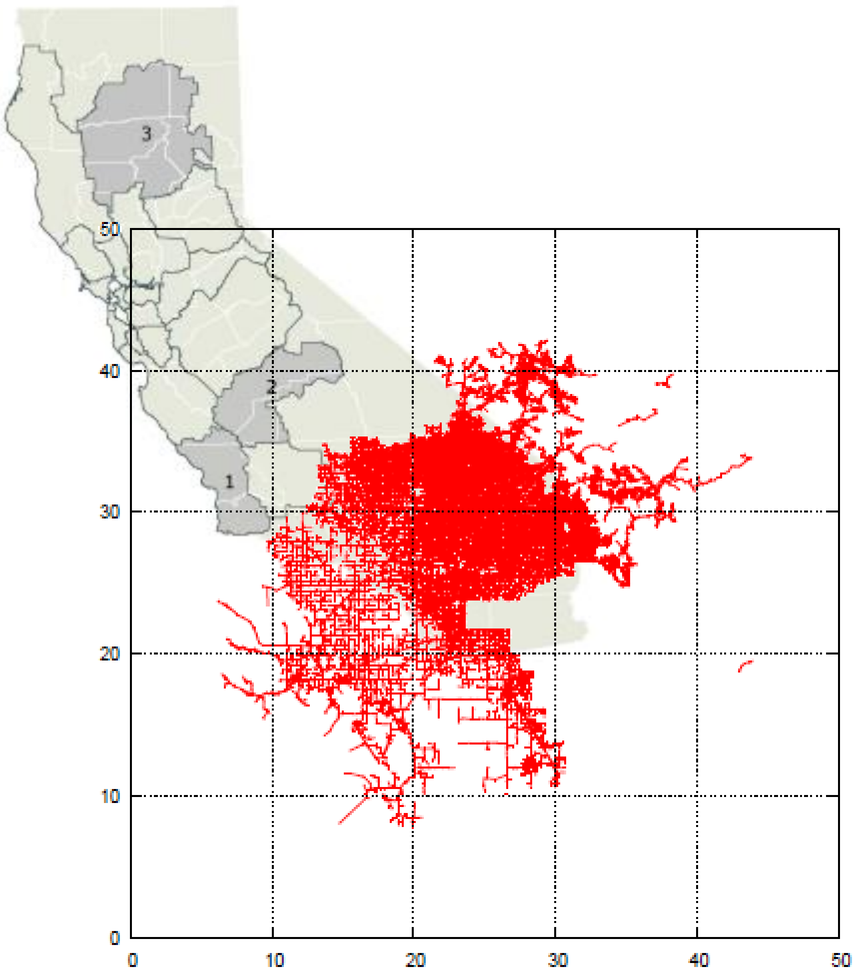
Prioritize

Group the compositions into uniformly spaced hyper-cubes

Prioritize based on number of samples

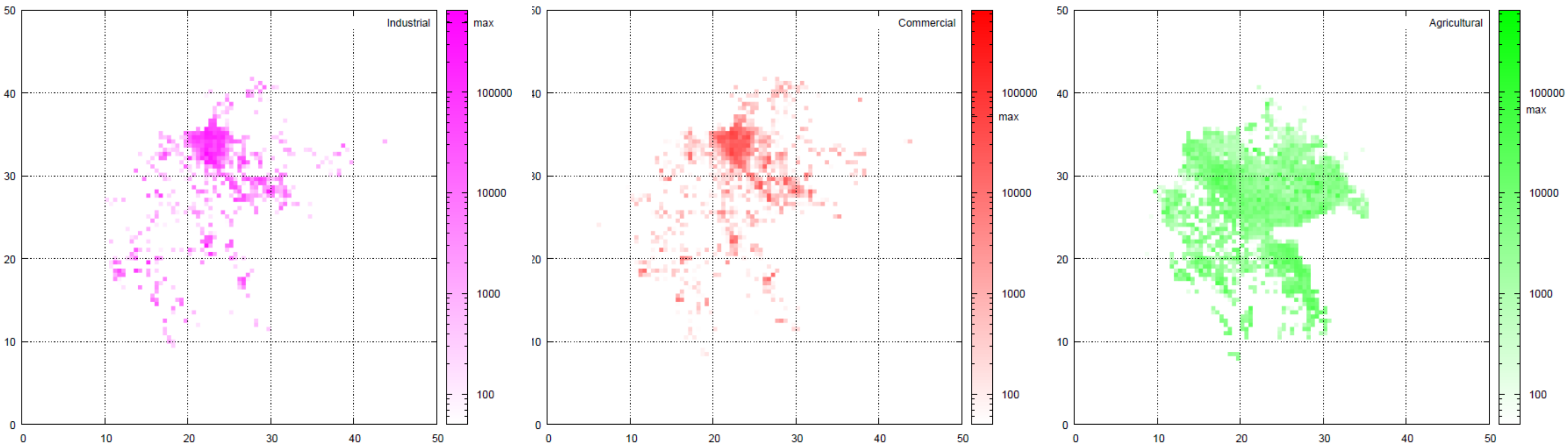
Average samples within each cube

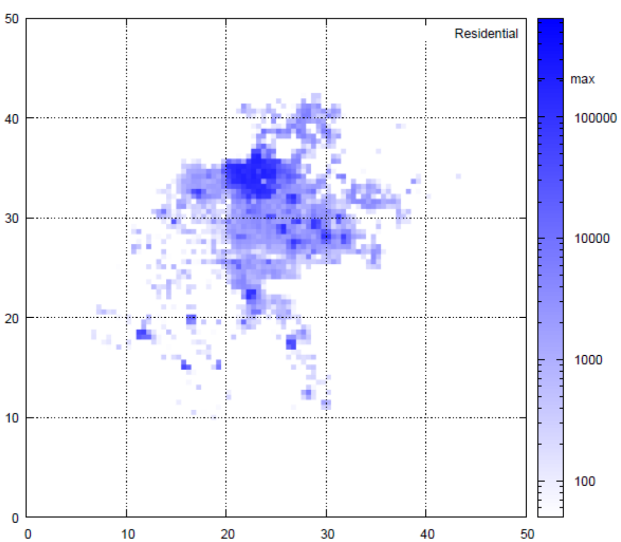
Three load zones, 557 feeders, 1396 reclosers, 14,821 PV sites, 538,800 load points

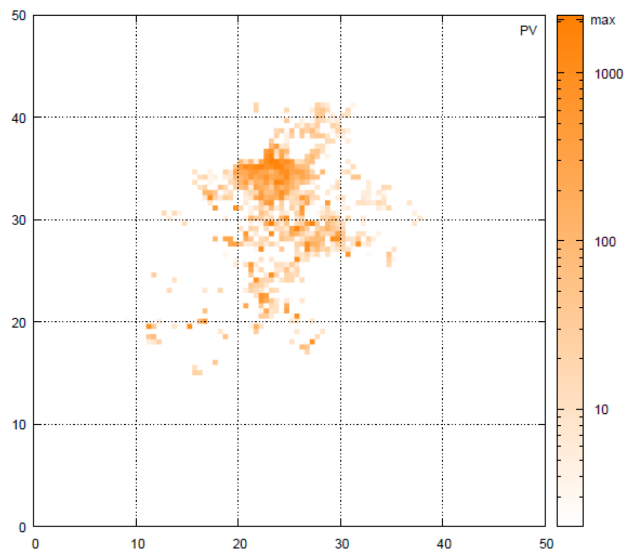


Attribute/Metric	Zone 1	Zone 2	Zone 3
Number of substations	27	66	64
Number of distribution feeders	84	325	148
Total circuit miles [mi]	1774	4101	3238
Total land area served [sqmi]	92.3	190.7	174.2
Number of load points (1000s)	114.2	235.3	189.3
Total load [connected MVA]	2647.3	7123.6	3085.1
Total load [MWh/day]	7253.7	29359.8	8372.8
Residential [%]	36.5	42.2	55.9
Commercial [%]	12.6	6.1	6.0
Industrial [%]	37.4	29.9	27.4
Agricultural [%]	13.4	21.4	10.5
Other [%]	0.1	0.4	0.2
Number of power-factor correction capacitors (including fixed and switched)	394	1465	702
Total reactive compensation [MVAr]	308.5	1457.4	491.1
Fixed [% of total] (by MVAr)	24	16	15
Number of reclosers	258	593	545
Number of voltage regulators	124	356	254
Number of PV installations	3352	7948	3521
Total PV capacity [MW] (nameplate AC)	24.8	83.8	39.2
PV/Connected MVA load [%]	0.94	1.18	1.27

Spatial Correlation of PV and load



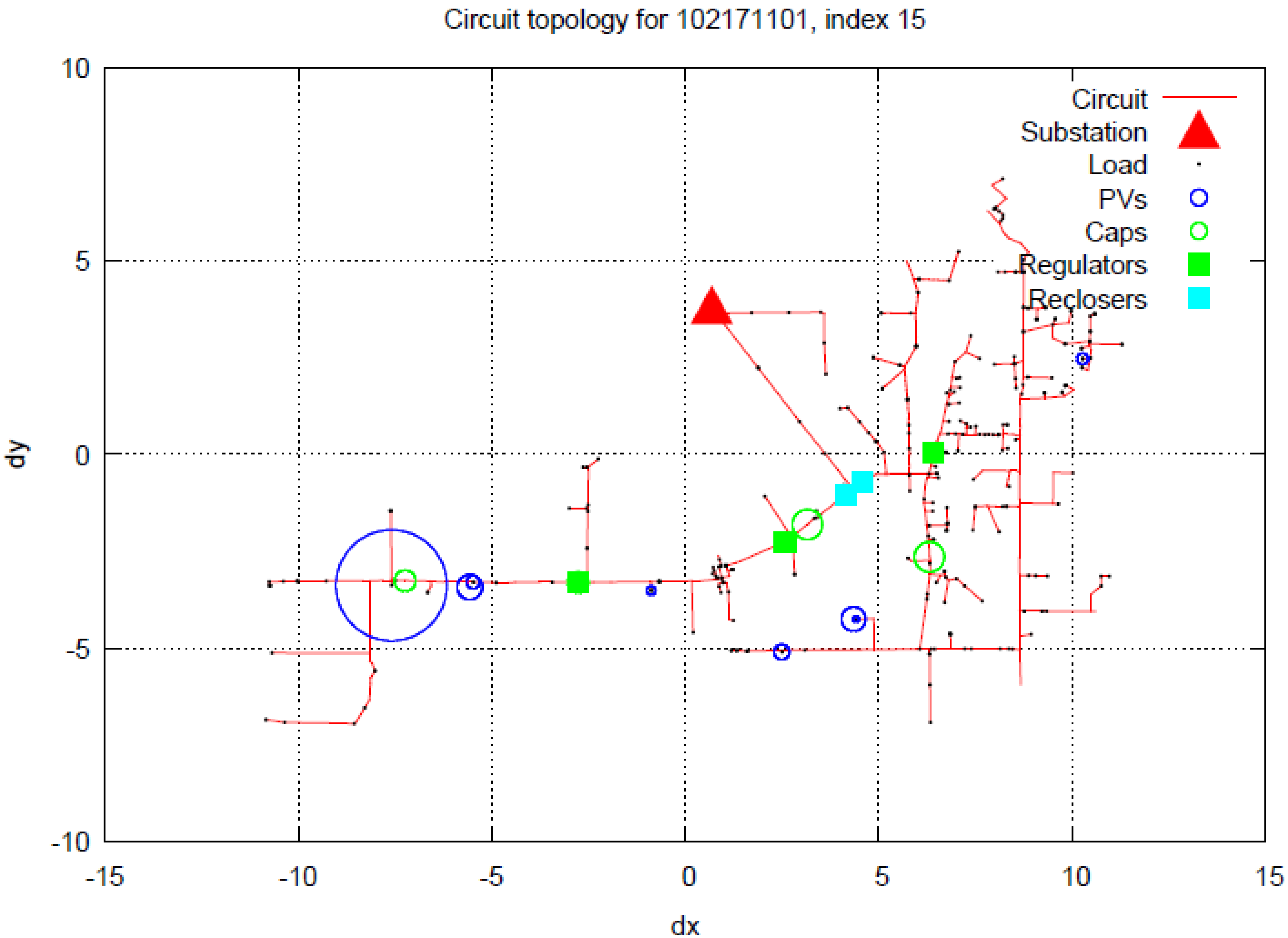




PV <u>is</u> correlated with residential and commercial loads

Decided to ignore, because penetration is a local phenomenon that can change with one installation

Section-scale analysis



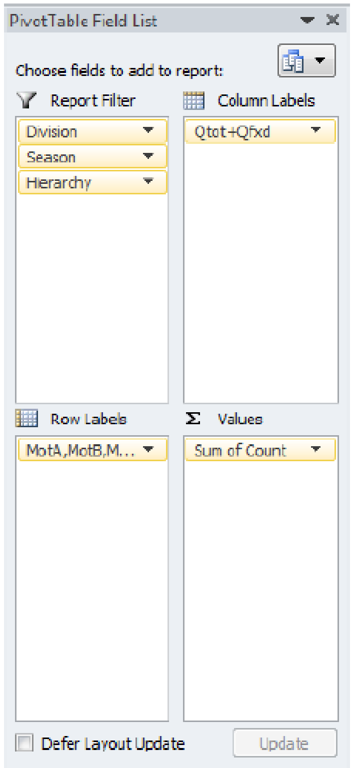
This circuit:
Feeder-Scale penetration: 82%

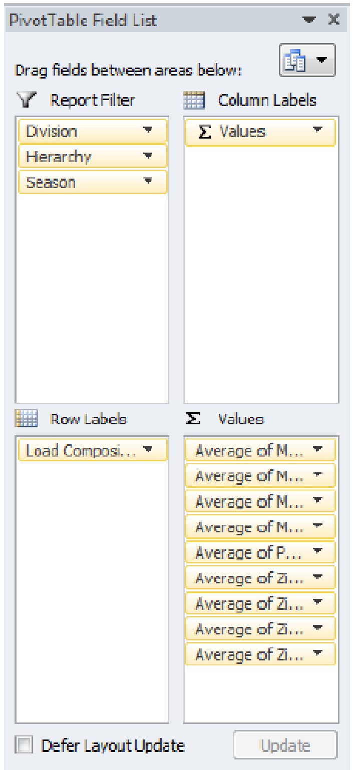
Section scale penetration: 349%, and 8.6%

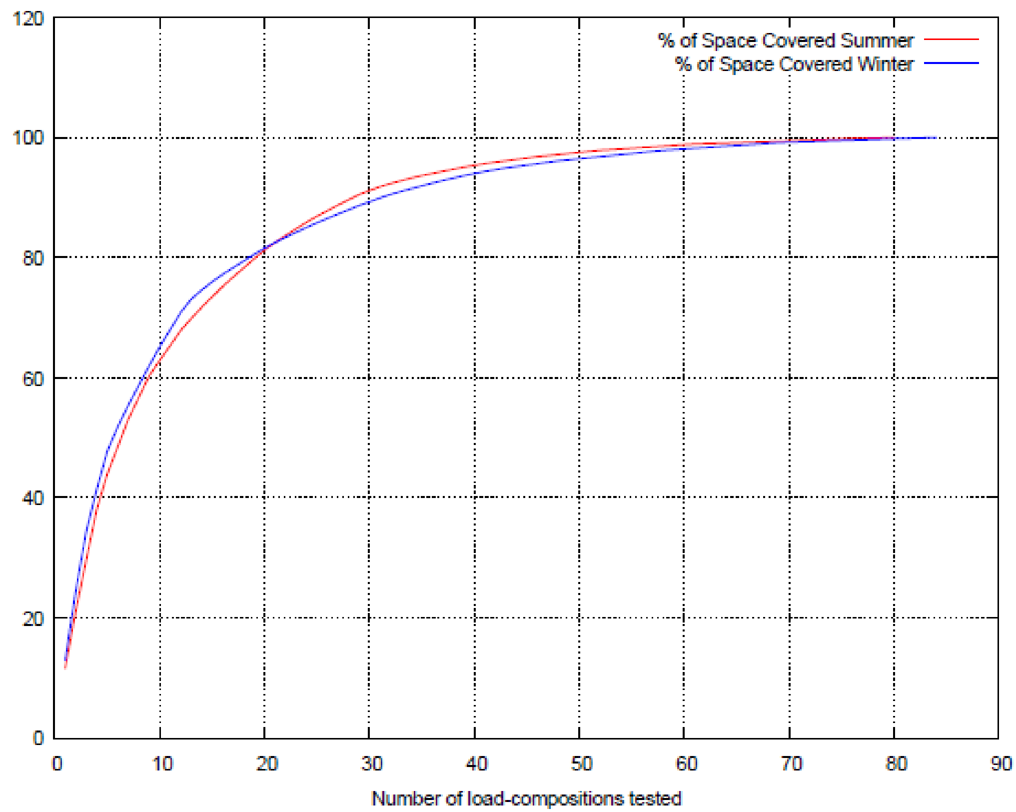
Overall:
100+% on 15 sections
50-100% on 39 sections

Max 617%

Rank compositions by frequency of occurrence







Two spreadsheets: Counts within hypercubes, and Averages within hypercubes

How many tests is that?

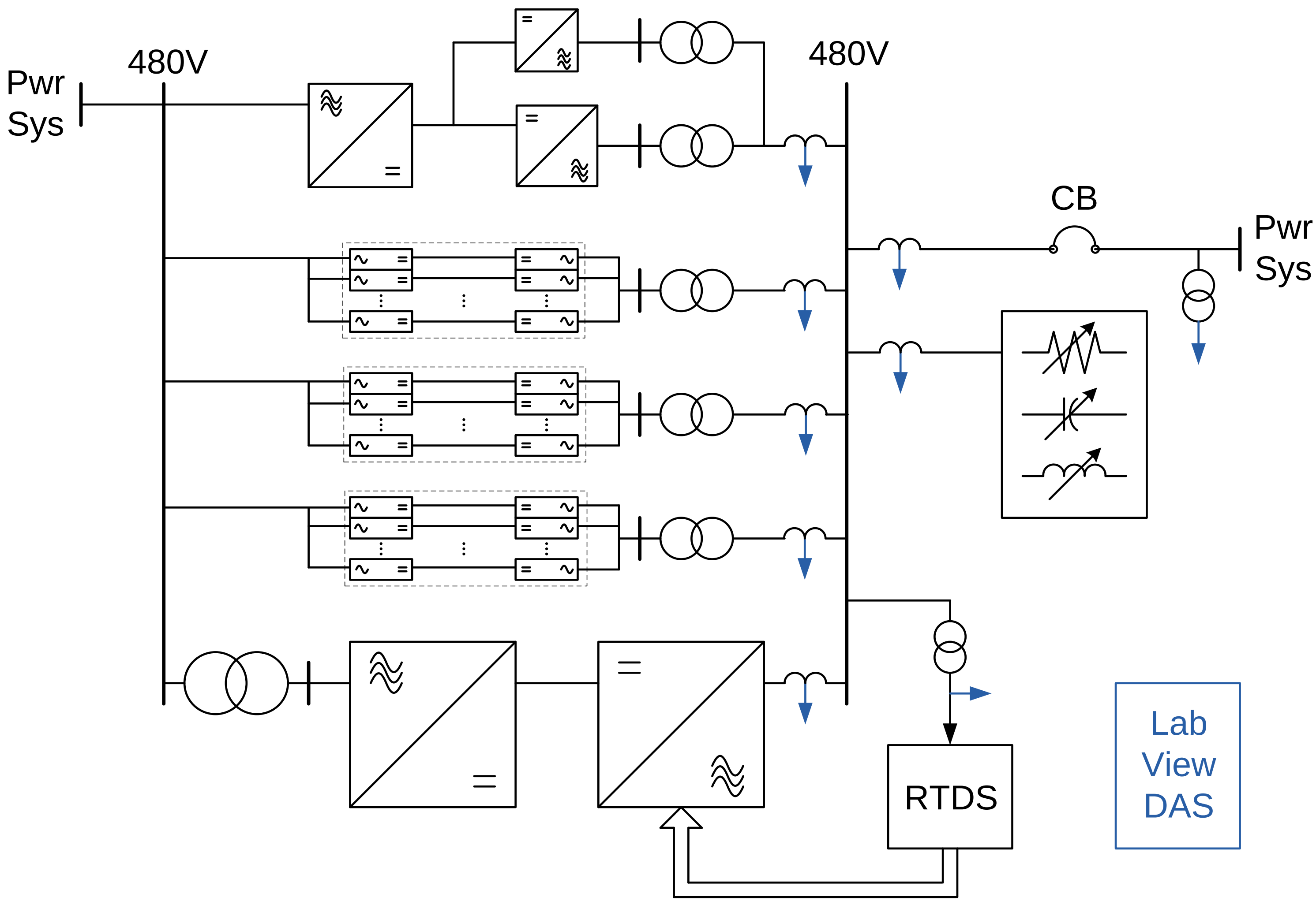
Table 5.2: *Required number of experiments to cover desired pecentages of load compositions space*

Desired Percentage of Space	80%	90%	95%
Summer			
Required number of compositions to test	20	29	39
× Q multiplier (5 values)	100	145	195
× PV penetrations (4 avg)	400	580	780
× PV penetrations (6 max)	600	870	1170
Winter			
Required number of compositions to test	19	32	44
× Q multiplier (5 values)	95	160	220
× PV penetrations (4 avg)	380	640	880
× PV penetrations (6 max)	570	960	1320
Total assuming 4 PV penetrations	780	1220	1660
Total assuming 6 PV penetrations	1170	1850	2490

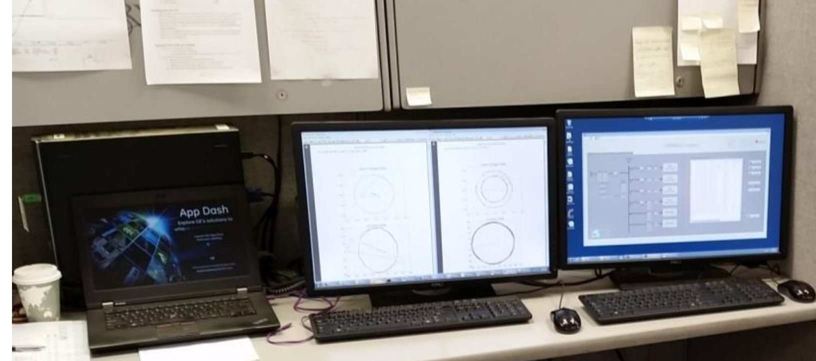
Duration of one test	10min	15min
#/hour	6	4
#/day	30	20
#/week	150	100
#/month	600	400
# of months for 1200 tests	2	3

Experimental Setup and Test Procedure

Test Facility: One-Line Diagram



Test Facility: Photographs



PV Inverters and Test Configurations

Unit Code	Number Available	Confirmed Output (kW)
x100	1	75
x45	1	42
r4kW 120Vac	4	4
r4kW 240Vac	10	3.8-4
r3.3kW 240Vac	6	3-3.3
r2.5kW 240Vac	10	1.5-2.5

Configuration Code	d	c	b	a
r4kW 120Vac	16 (4)	16 (4)	16 (4)	12 (3)
r4kW 240Vac	24 (6)	20 (5)	16 (4)	12 (3)
r3.3kW 240Vac	16 (5)	13 (4)	10 (3)	7 (2)
r2.5kW 240Vac	10 (4)	5 (3)	5 (3)	5 (3)
Total Power (kW)	**66**	**54**	**47**	**36**

Test Procedure Overview

1) Select a load composition from the priority list
   - Configure load model in RSCAD runtime
   - Record baseline P, Q seen by the RTDS, Amplifier, and LabView

3) Set PF to 0.95ind (by dialing the capacitive correction on the amplifier)

4) Set PV penetration to 108% (by starting the pre-determined group of PV inverters)

5) Run the experiment and capture data

6) Repeat for PV penetrations of: 100, 80, 61, 36% (restart tripped inverters, repeat from 4)

7) Screen for acceptance, repeat tests if required

8) Repeat for other PF choices: 0.98ind, 1.0, 0.98cap

9) Upload to cloud

10) Repeat for other load compositions from the priority list

Streamlined Execution and Quality Assurance

Applied Technology Services

	A	B	C	D	E	F	G	H	I	J	K	L	
1	0.3,0.0,0.3,0.0,0.0,0.1,0.0			2) Configure Definitions sheet			3) Save as TestLogSummer01.xlsx {Summer | Winter} {01 | 02 | ...} Season and prior						
2	Operator	DG Code	P3ph (B2) [kW]	Pwall (B1) [kW]	Pgen [kW]	Penetration [%]	RLC [kW]	GE Amp RTDS File	QC load [kVAr]	PF load []	LabView File Nums	Normal?	Comment
3	6/17/2015												
4		xoff a	0	31.2	31.2	26%	119.6	n/a	25.7	.950		s	LimRTDS = 0.93, L
5	AXEy	xoff b	0	42.8	42.8	36%	119.6	n/a	25.7	0.95	294-295	y	
6	AXEy	x45 a	42	31.2	73.2	61%	119.6	n/a	25.7	0.95	292-293	y	
7	AXEy	x45 c	42	53.4	95.4	80%	119.6	n/a	25.7	0.95	290-291	y	
8	AXEy	x100 b	76	42.8	118.8	99%	119.6	n/a	25.7	0.95	288-289	y	
9	AXEy	x100 c	76	53.4	129.4	108%	119.6	n/a	25.7	0.95	286-287	y	
10		x100 d	76	62.4	138.4	116%	119.6	n/a	25.7	0.95		s	
11													
12		xoff a	0	31.2	31.2	26%	119.6	n/a	40.7	.980		s	LimRTDS = 0.93, L
13	AXEy	xoff b	0	42.8	42.8	36%	119.6	n/a	40.7	0.98	304-305	y	
14	AXEy	x45 a	42	31.2	73.2	61%	119.6	n/a	40.7	0.98	302-303	y	
15	AXEy	x45 c	42	53.4	95.4	80%	119.6	n/a	40.7	0.98	300-301	y	
16	AXEy	x100 b	76	42.8	118.8	99%	119.6	n/a	40.7	0.98	298-299	y	
17	AXEy	x100 c	76	53.4	129.4	108%	119.6	n/a	40.7	0.98	296-297	y	
18		x100 d	76	62.4	138.4	116%	119.6	n/a	40.7	.980		s	
19	6/18/2015												
20		xoff a	0	31.2	31.2	26%	119.6	n/a	65.0	1.0		s	LimRTDS = 0.93, L
21	AXEy	xoff b	0	42.8	42.8	36%	119.6	n/a	65.0	1.0	315	?	Current graph not
22	AXEy	x45 a	42	31.2	73.2	61%	119.6	n/a	65.0	1.0	313-314	y	
23	AXEy	x45 c	42	53.4	95.4	80%	119.6	n/a	65.0	1.0	311-312	y	
24	AXEy	x100 b	76	42.8	118.8	99%	119.6	n/a	65.0	1.0	309-310	y	
25	AXEy	x100 c	76	53.4	129.4	108%	119.6	n/a	65.0	1.0	306-308	y	
26		x100 d	76	62.4	138.4	116%	119.6	n/a	65.0	1.0		s	
27													
28		xoff a	0	31.2	31.2	26%	119.6	n/a	89.3	.980		s	LimRTDS = 0.93, L
29	AXEy	xoff b	0	42.8	42.8	36%	119.6	n/a	89.3	0.98	324-325	y	
30	AXEy	x45 a	42	31.2	73.2	61%	119.6	n/a	89.3	0.98	322-323	y	
31	AXEy	x45 c	42	53.4	95.4	80%	119.6	n/a	89.3	0.98	320-321	y	
32	AXEy	x100 b	76	42.8	118.8	99%	119.6	n/a	89.3	0.98	318-319	y	
33	AXEy	x100 c	76	53.4	129.4	108%	119.6	n/a	89.3	0.98	316-317	y	
34		x100 d	76	62.4	138.4	116%	119.6	n/a	89.3	.980		s	
35													
36		xoff a	0	31.2	31.2	26%	119.6	n/a	104.3	.950		s	
37		xoff b	0	42.8	42.8	36%	119.6	n/a	104.3	.950		s	
38		x45 a	42	31.2	73.2	61%	119.6	n/a	104.3	.950		s	

Time per test: 6-10 minutes

- Includes setting stable testing condition, initial visual inspection, creating island, logging and transferring data
- The limiting factor is the restart time of inverters

Quality assurance

- Baseline operating point captured from three independent measurement systems (RTDS, GE Amplifier, LabView)
- RSCAD entries captured as a screen shot for traceability
- LabView file names captured into TestLog spreadsheet along with comments.

Test Engineer's Cockpit

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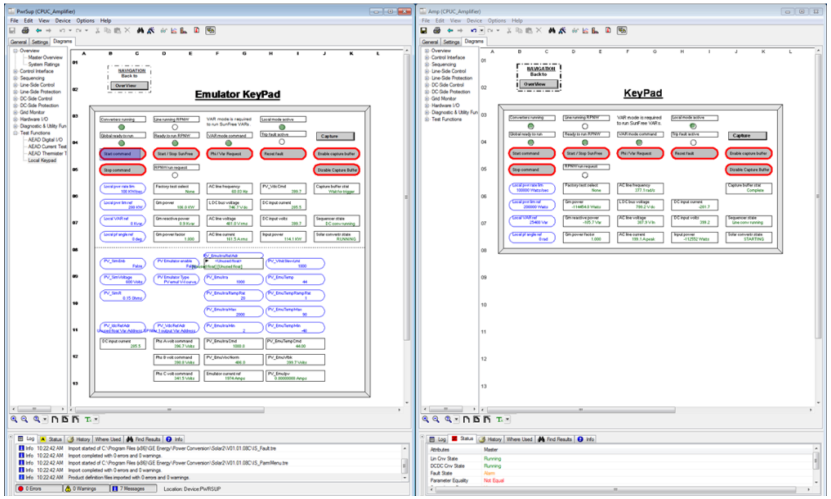
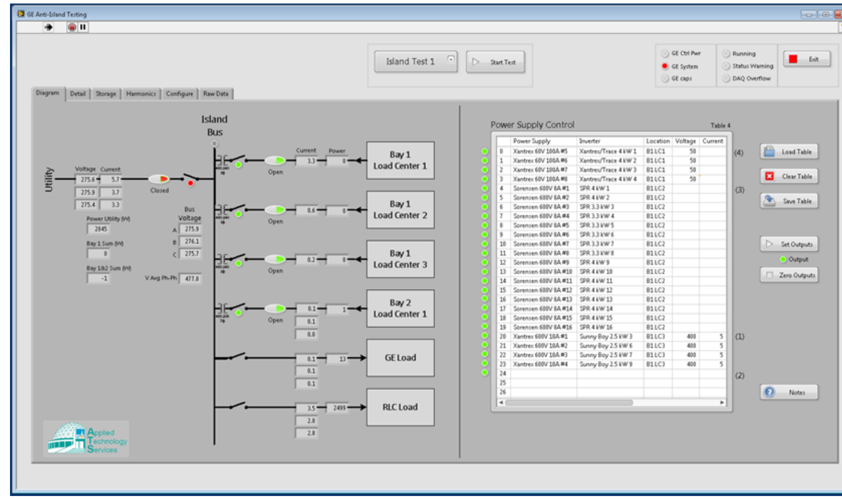
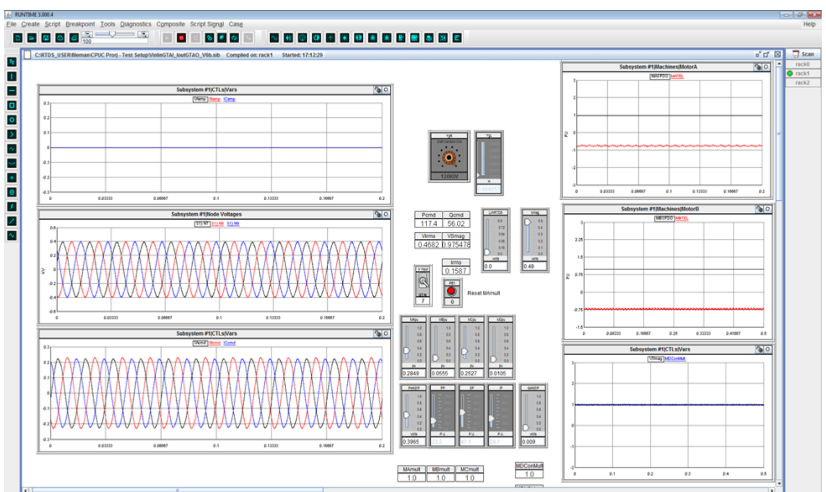






The Results and the Impact on PG&E Interconnection Process

Analysis of Test Results

Prepare

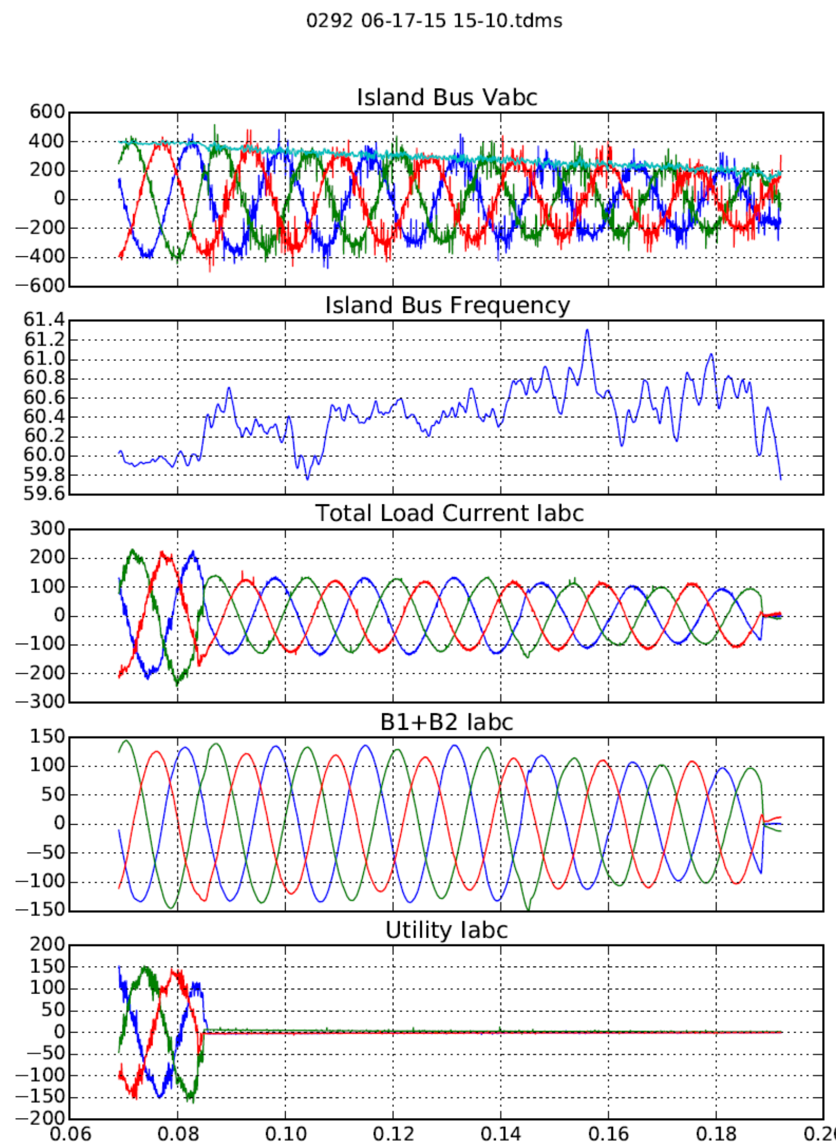
- Associate recordings with test conditions
- Calculate RMS values, P, Q, f,… from voltages and currents

Extract Attributes

- Determine onset and cessation of island
- Compute scalar attributes of tests

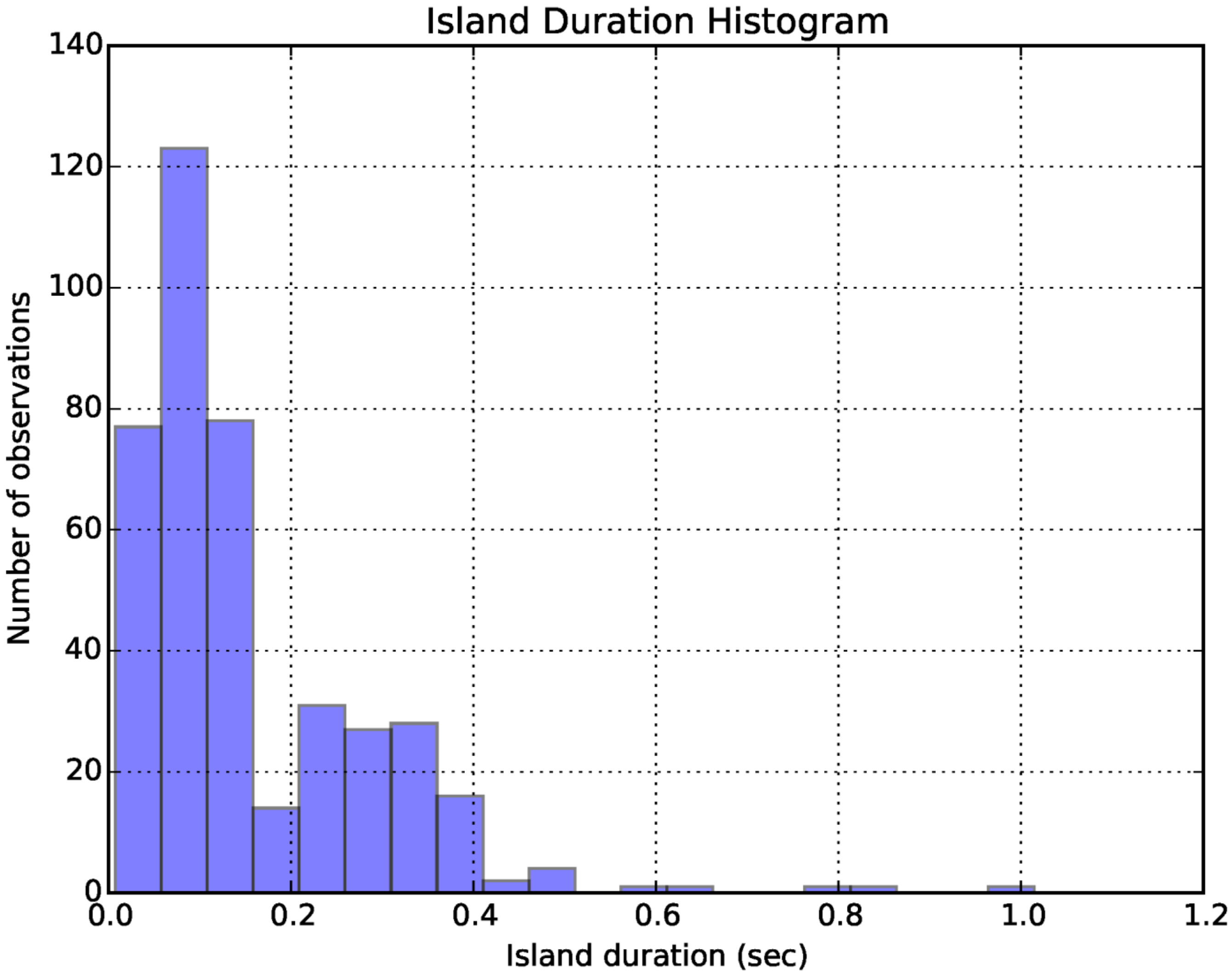
Analyze Trends

- Group, pivot, and visualize the data to determine relationships and trends

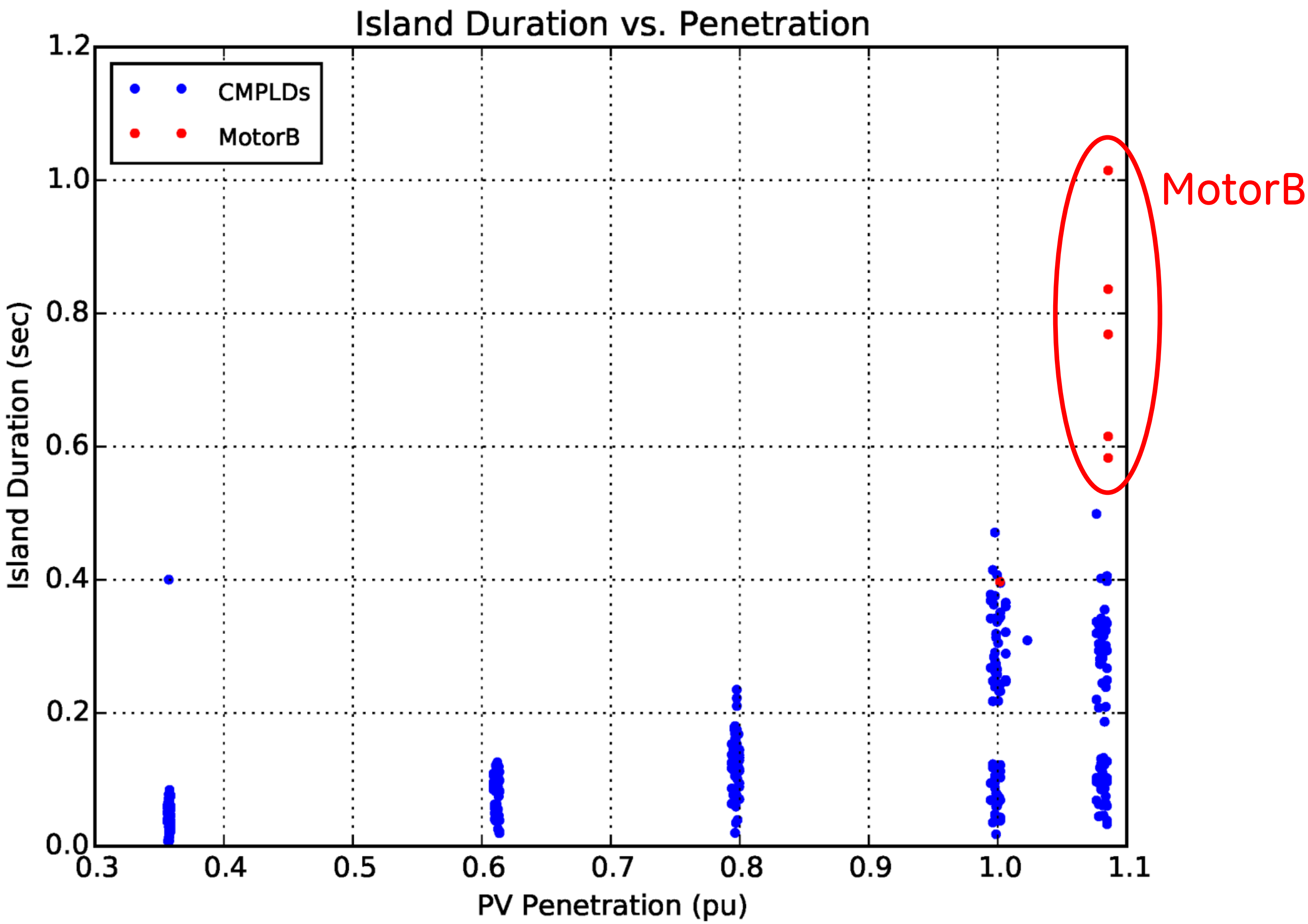


Measured island durations

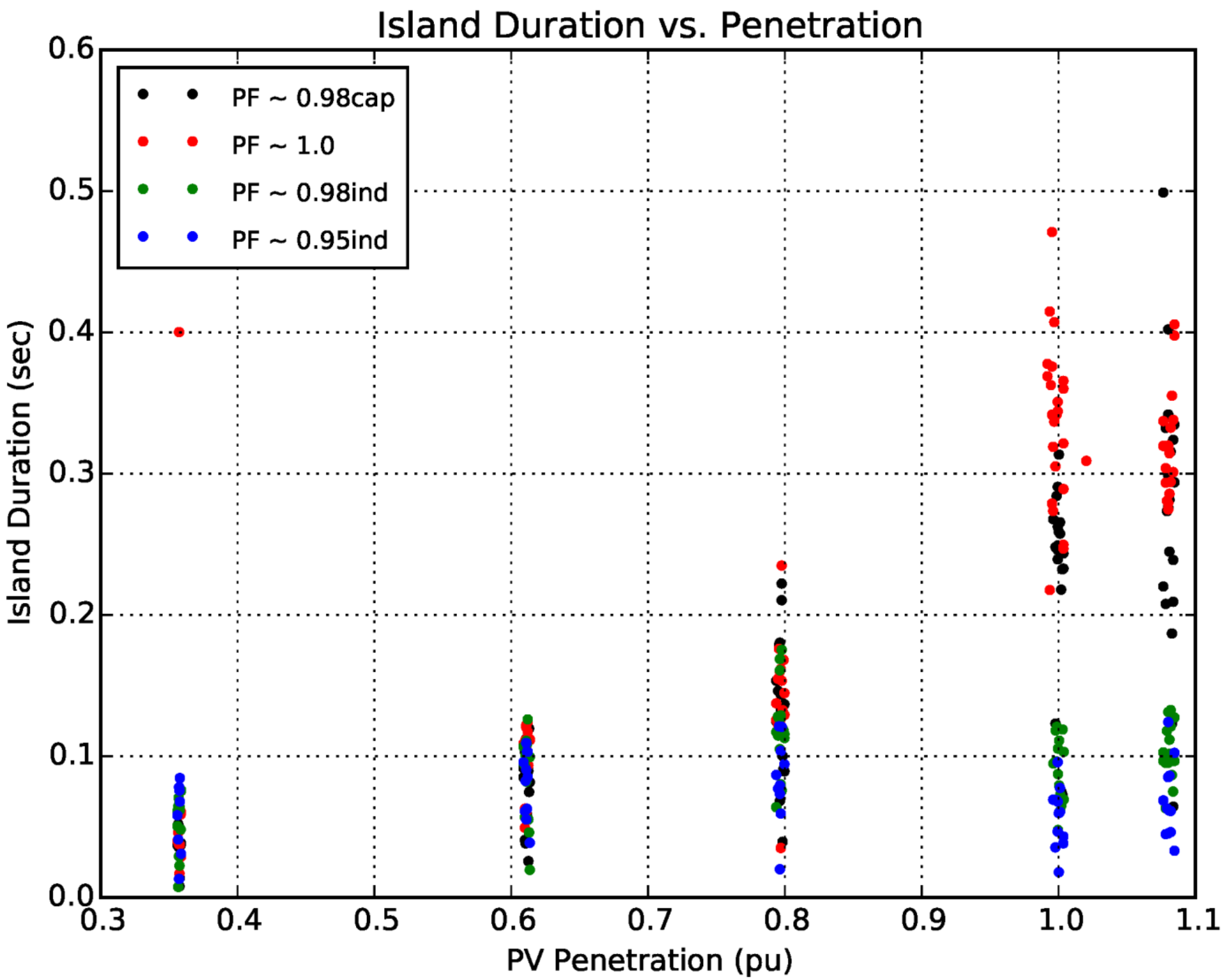
UL1741 limit is 2sec



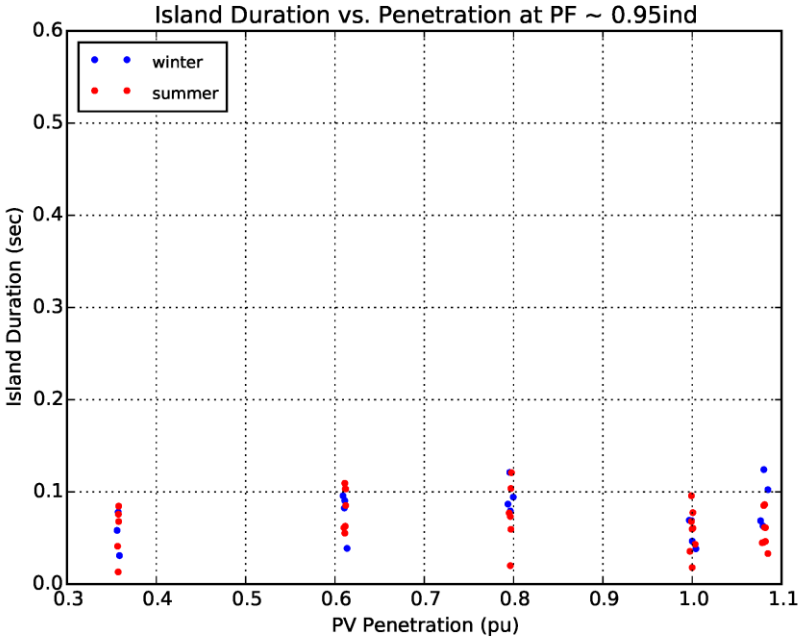
Pure motor loads outlast composite loads

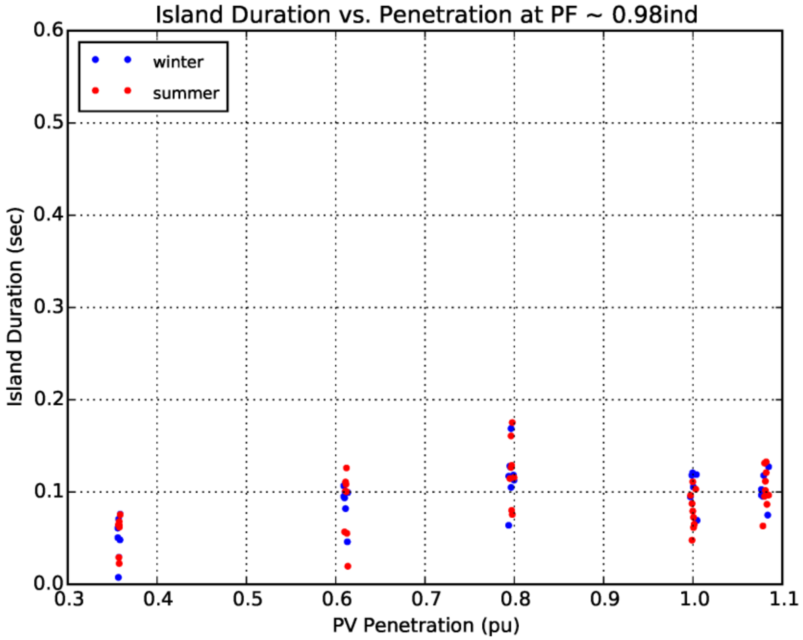


Impact of load power factor on duration

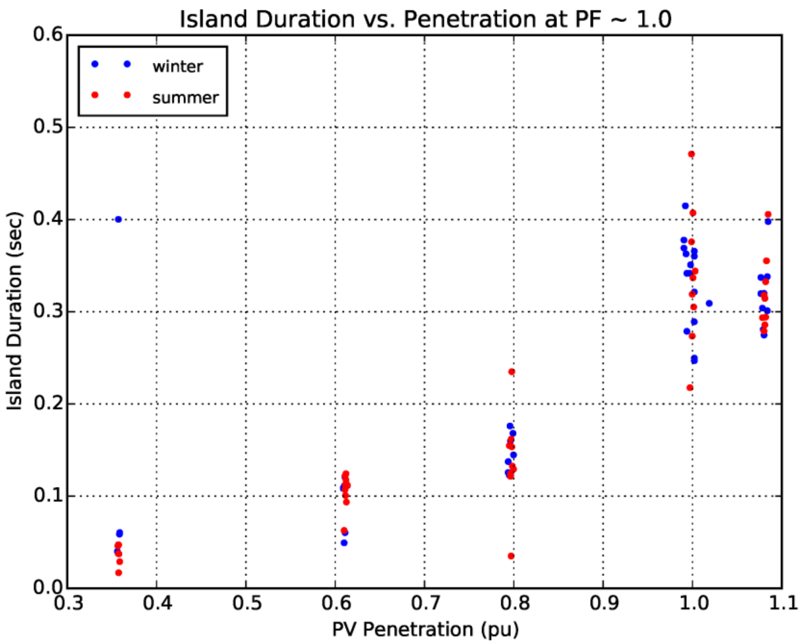


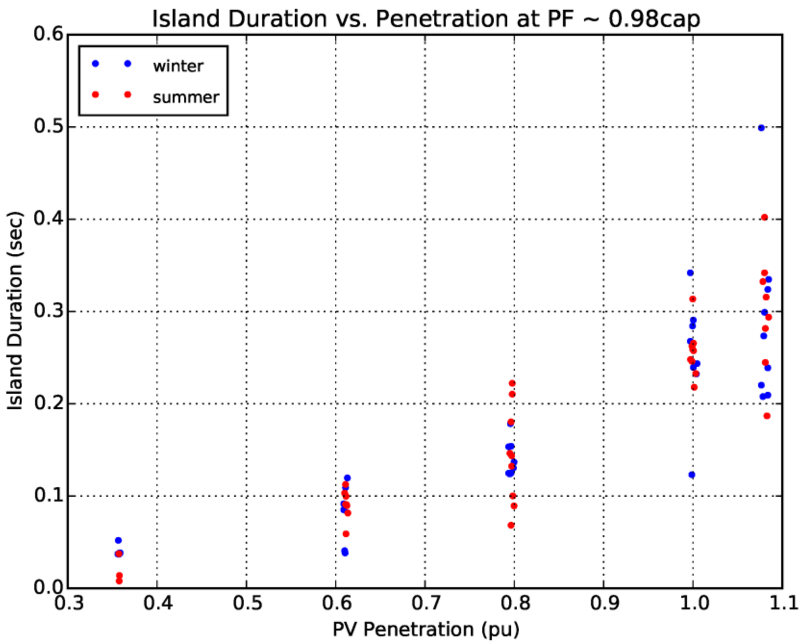
Inductive power factors:
Impact of season via load composition





Unity and overcompensated PFs: Impact of season via load composition





Impact on PG&E Interconnection Process
(recommendations)

- **In initial review:** Raise screening limit from 15% peak load to 60% of estimated simultaneous load (estimate using C-EDSA conversion factors)
- **In supplemental review:** Keep existing MDL screen when SCADA data available, allow 80% of estimated simultaneous load by maintaining section PF ≤ 0.98
- **In detailed review:** Allow up to 105% of simultaneous load without special mitigation by de-tuning circuits to maintain PF between 0.95 and 0.98 inductive (Please note that operating and maintaining PF at this level is a special mitigation measure for islanding. 15% screen is also used to flag reverse flow and associated overvoltage conditions. So, reverse flow effects will also need to be checked during the interconnection review.)

Contingent on confirming actual circuit performance in field tests!

Summary and the Next Steps

Summary and Next Steps

Accomplishments:

- ✓ Defined a novel analysis process to prioritize 7-dimensional data based on frequency of occurrence
- ✓ Created the most sophisticated MW-scale load model in the utility industry
- ✓ Enabled quantifying the behavior of the highly dimensional space by highly streamlined testing

Next steps:

Validate two key assumptions:

- Tested inverters are a representative sample of PV fleet on the system
- The WECC load models are representative of circuit loads

Revise PG&E interconnection rules to take advantage of the findings

Disseminate to utility industry (Distributech 2016 paper)

Assess the impact of new inverter functionality recommended by SIWG

http://www.calsolarresearch.ca.gov/

Thank you!