Advanced Distribution Analytics Services Enabling High PV Penetration

California Solar Initiative RD&D Solicitation #4

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Executive Summary:

- Background:
  - CA's ambitious Renewable Portfolio Standard (RPS)
  - Distributed PV model (not large scale)
- Goal of project:
  - Improve the economics of solar technology by:
    - Determining native limits of circuits
    - Identifying technology paths forward for PV to 100%
- Process:
  - Build representative circuit models in GridLAB-D, deploy PV systems with adoption model, determine native limits of PV with defined operational limits, investigate mitigation paths
- Results
  - Identified limiting violations and mitigation strategies

Agenda/Schedule

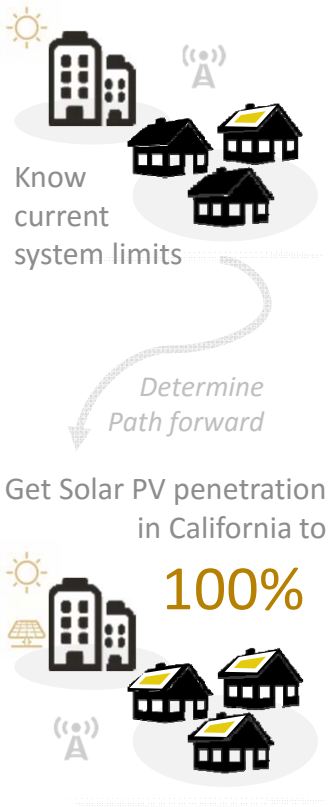
Topic	Time Start	Time End
Part 1:	**10:00**	**10:35**
Project overview & Context	10:00	10:05
Clustering	10:05	10:10
Modeling	10:10	10:25
- 10 minute Q&A break-	10:25	10:35
Part 2:	**10:35**	**11:10**
Native Limits	10:35	10:50
Mitigation	10:50	11:00
- 10 minute Q&A break -	11:00	11:10
Part 3:	**11:10**	**12:00**
GridUnity Platform Overview	11:10	11:20
Optimization Analysis Demonstration	11:20	11:50
Q&A	11:50	12:00

CSI RD&D Program Key Principals

- Improve the economics of solar technologies by reducing technology costs and increasing system performance
- Focus on issues that directly benefit California, and that may not be funded by others
- Fill knowledge gaps to enable successful, wide-scale deployment of solar distributed generation technologies

Project Goals

Streamline the interconnection process for high penetration of PV to meet California's RPS* goals by:



- Better understanding current grid limits for solar penetration (native limits)
- Develop technology strategies for California feeders to obtain 100% PV penetration
- Create a cloud-based tool to study and analyze solar PV feeder limits

These should help **reduce time and cost** required to integrate high penetration of PV on numerous feeders

*RPS- renewable portfolios standard

Project Partners

For more information, including project reports, see: http://www.calsolarresearch.ca.gov/

Determine native Solar PV penetration levels for representative feeders and identify cost-effective mitigation strategies for higher levels of Solar PV

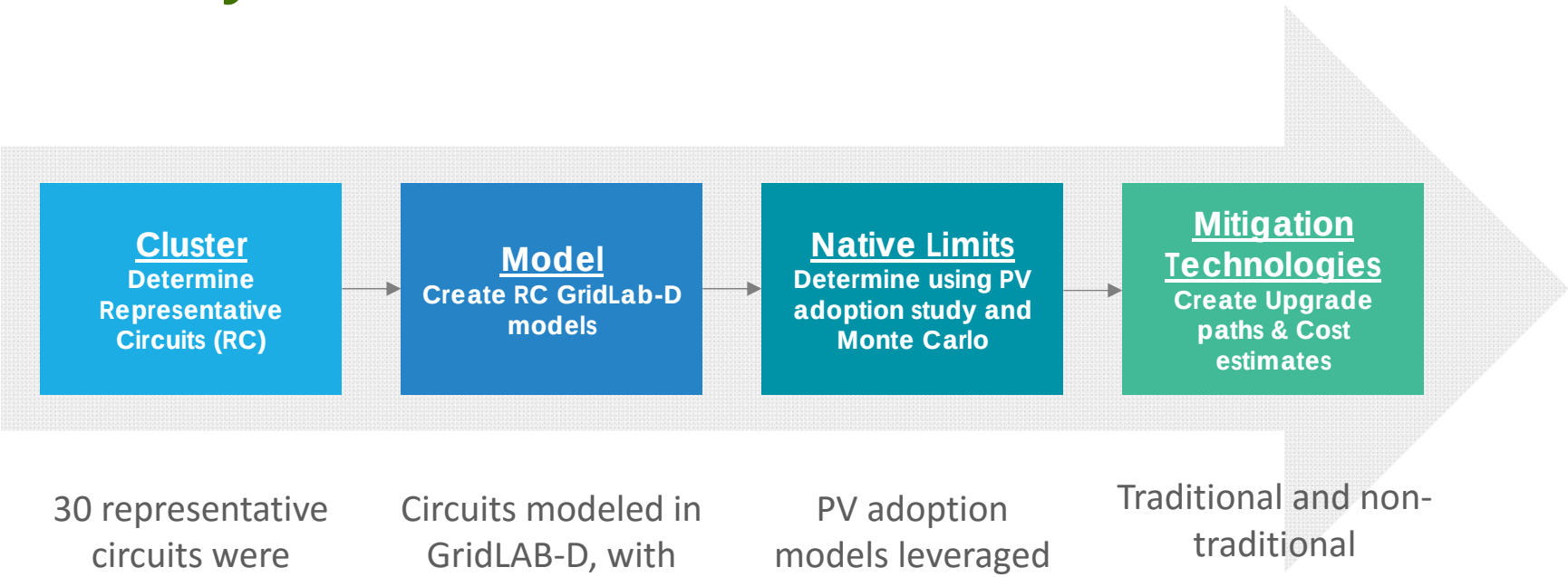
Provide distribution model, interconnection process, validation of results, and demonstration of field interconnection

Provide GridUnity software to analyze impacts, communicate to stakeholders, and manage interconnection process

Project Sponsors

California Public Utilities Commission, California Solar Initiative, Itron

Study Process



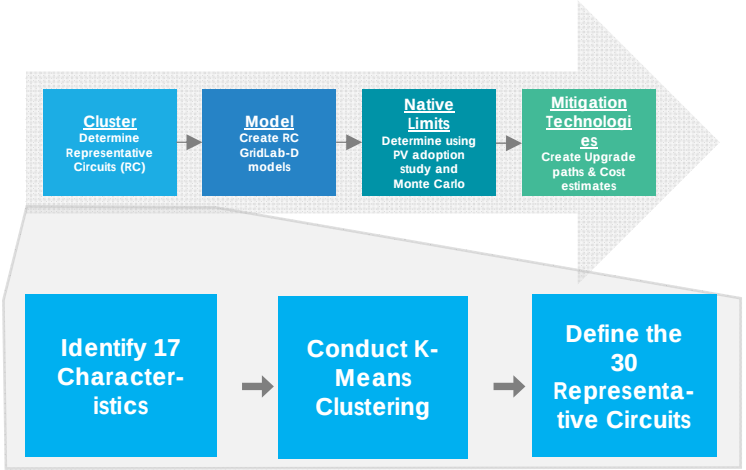
30 representative circuits were determined using K-Means clustering. (15 of the most representative were used in this study)

Circuits modeled in GridLAB-D, with behind the meter loads. Models calibrated against SCE customer usage data.

PV adoption models leveraged to determine Native limits based on 10 operational constraints.

Traditional and non-traditional mitigation strategies developed for circuit upgrades to achieve 100% PV penetration.

Clustering



Using K-Means clustering, could represent

+ 4,500 circuits with **30** Representative circuits

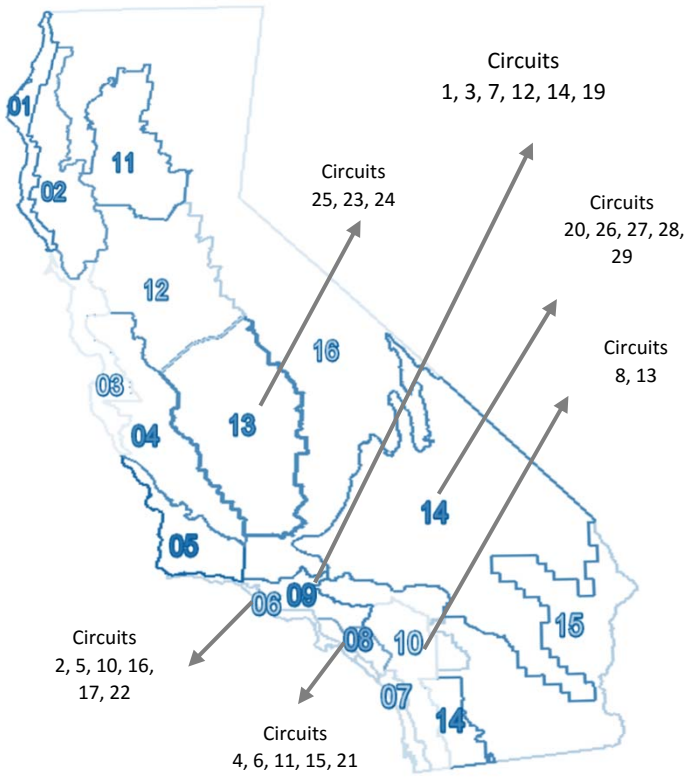
Top **15** representative circuits represent **63%** of SCE circuits

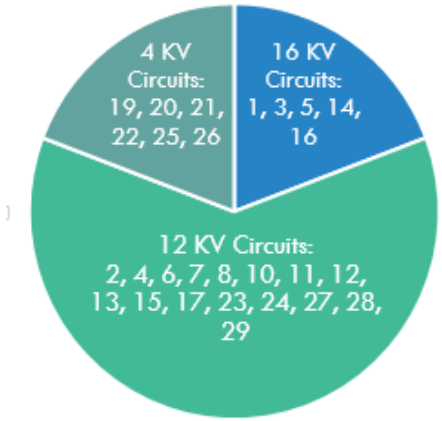
Table 2.1: Scaling Importance of Circuit Dimensions Used in K-Means clustering

Dimension	Scale	Dimension	Scale
Voltage Class	8	% of Energy Sold - Agricultural Customers	2
Climate Zone	8	Total Number of Customers	2
Connected Service Transformer Capacity	4	% of Residential Customers PRIZM High Income	2
Circuit Peak Load	4	% of Residential Customers PRIZM Medium Income	2
Miles of 3 Phase Circuit	2	% of Residential Customers PRIZM Low Income	2
Miles of 1 or 2 Phase Circuit	2	Number of Voltage Regulators	1
% of Energy Sold - Residential Customers	2	Number of Capacitor Banks	1
% of Energy Sold - Commercial Customers	2	Number of Circuits Tie points	1
% of Energy Sold - Industrial Customers	2		

The Mix – Circuit Variability

Representation of California Climate Zones

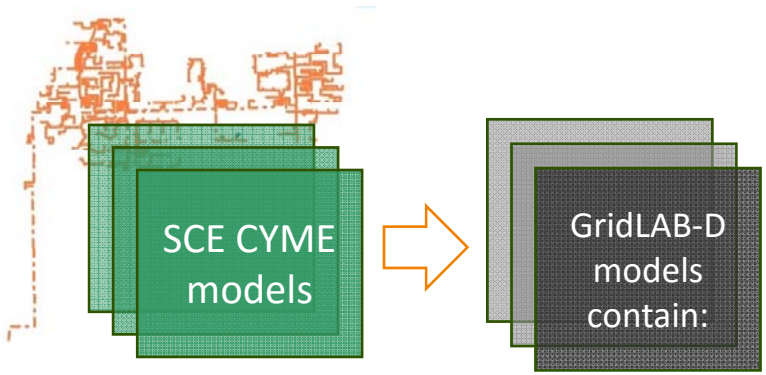


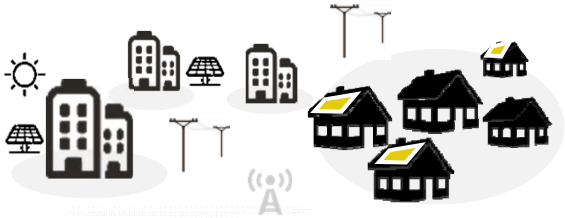


- Customer type breakdown
- Customer usage
- Geography
- Voltage class
- Socioeconomic class *
- Life stage *

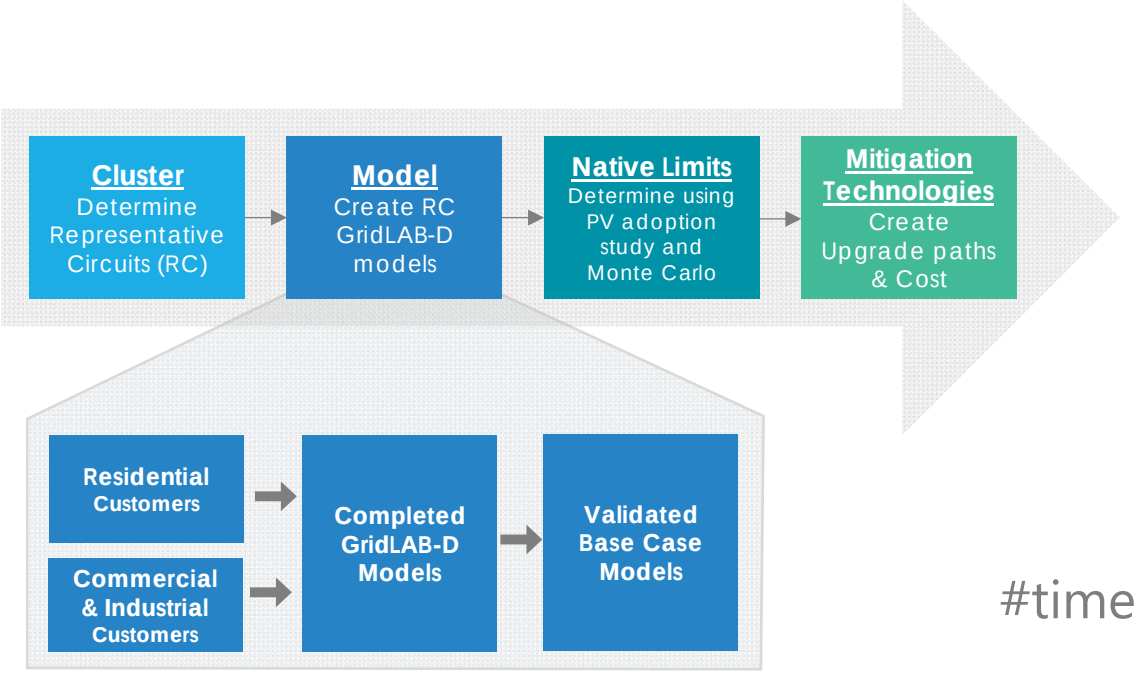
* Used in modeling, not in clustering

GridLAB-D Models





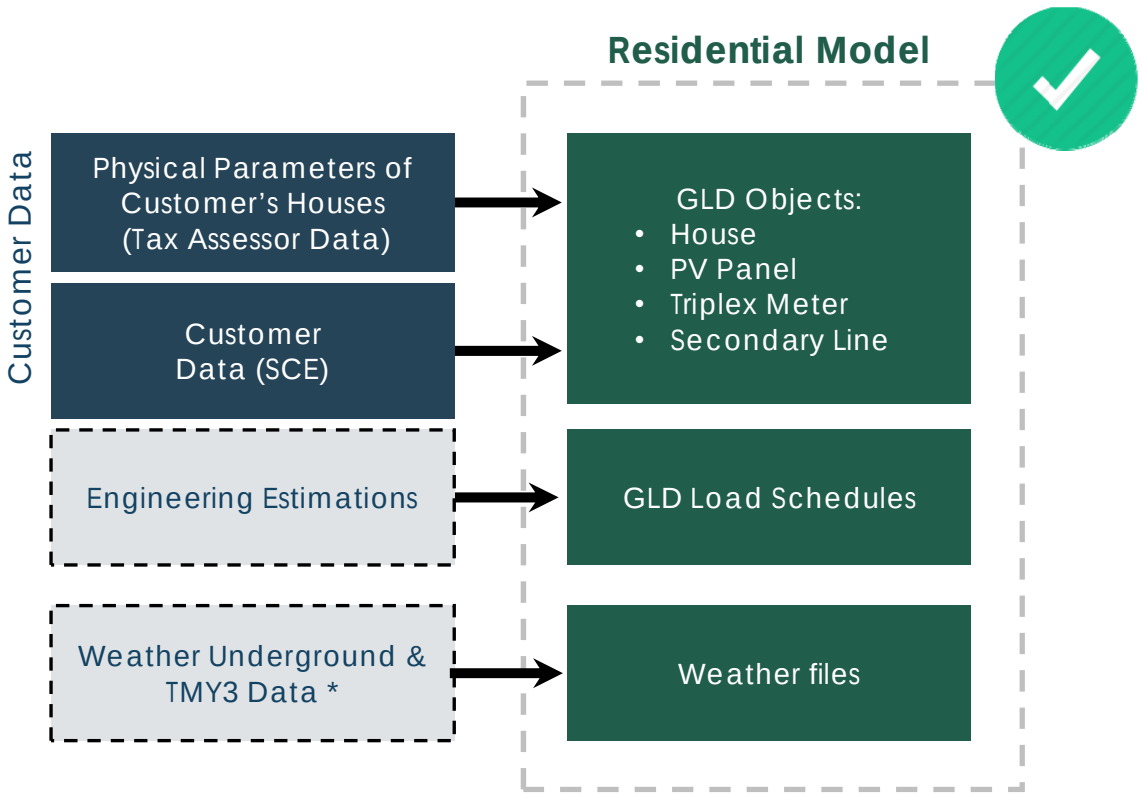
- All customers (residential & commercial)
- Device loads schedules (HVAC, lighting, etc.)
- Distribution system equipment (e.g. transformers)



Manual & Automatic conversion process #timeconsuming

Residential Modeling

The science and art of it…



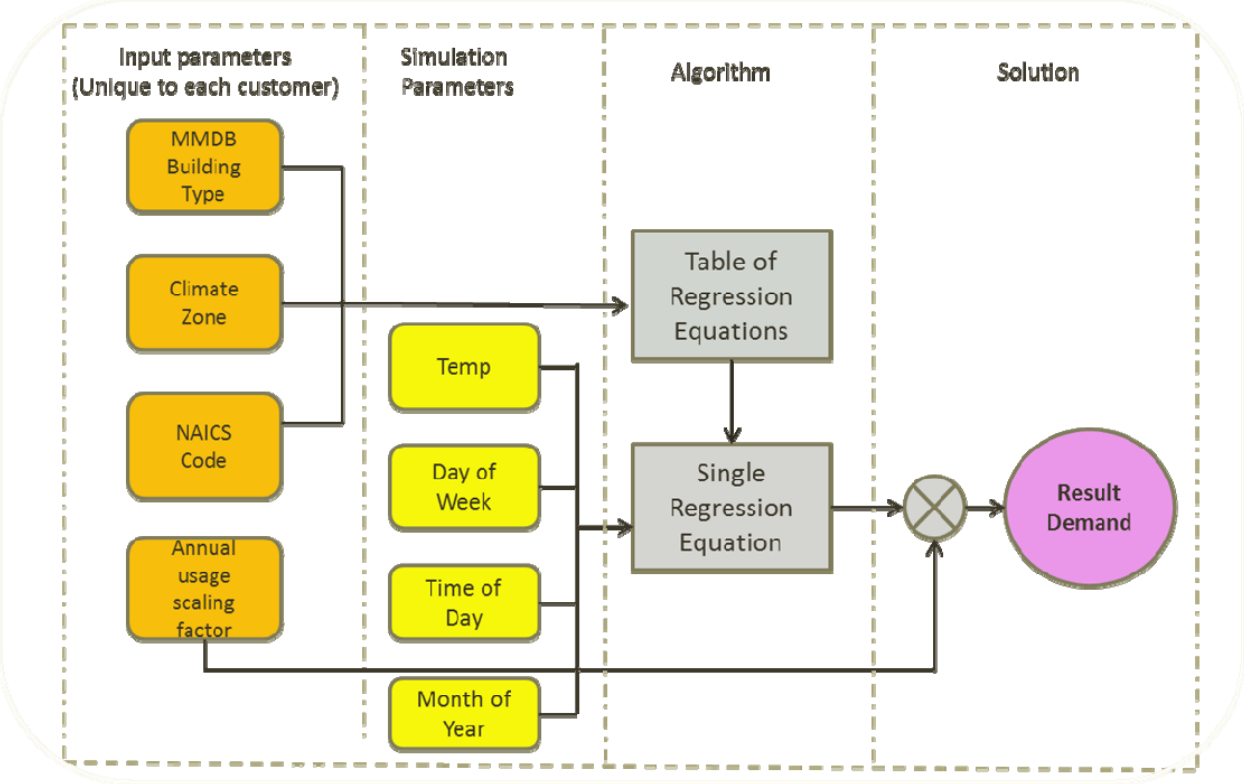
Models calibrated against customer usage (binned as shown below) within 10%

Table 3.1
Usage Bins for Validation (kWh per month)
Bin 1: < 200
Bin 2: [200, 400)
Bin 3: [400, 600)
Bin 4: [600, 800)
Bin 5: [800, 1000)
Bin 6: > 1000

Load schedules determined heuristically & iteratively.
HVAC, occupant load, fans, pool pumps, lighting, ovens

Commercial Modeling

More science than art…



Commercial loads were modelled via regression equations that were fit to historical customer AMI demand and weather data.

Load schedule for HVAC determined statistically.

PV Adoption

PV was modelled as distributed systems based on customer PV adoption likelihood.

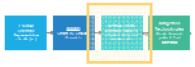
- Residential PV Adoption based on daily usage of customers.
- Commercial & Industrial PV adoption based on building type.

Monte-Carlo simulations then used to deploy adoption scenarios. This allows for statistically diverse scenarios.

This study differs from other studies because of this distributed PV model, whereas past studies look at large scale system deployment on each feeder. This difference makes the results of these studies reflect more accurately the realistic scenarios possible.

10 min break – Q&A

Finding Native Limits- Methodology



Step 1: Define key metrics

Native Limit	Determined when any of the operational limits is reached in a PV adoption simulation. Level 1 limit: violations on the secondary Level 2 limit: violations on the primary
PV Penetration	the ratio of the installed inverter nameplate rating to the peak circuit load
Operational Limits	(see next slide)
Min. Simulations	50 scenarios

Step 2: Clear base case models of violations

Step 3: Deploy Monte-Carlo PV adoption models

Step 4: Run simulations – determine level 1 & 2 limits

Defined Operational Limits

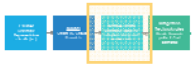
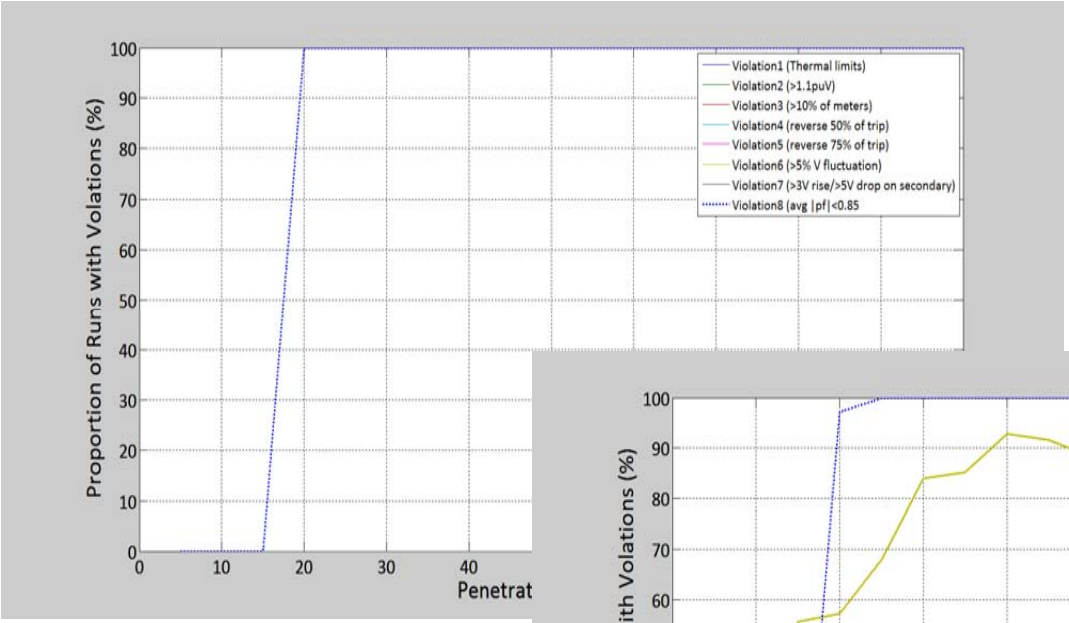


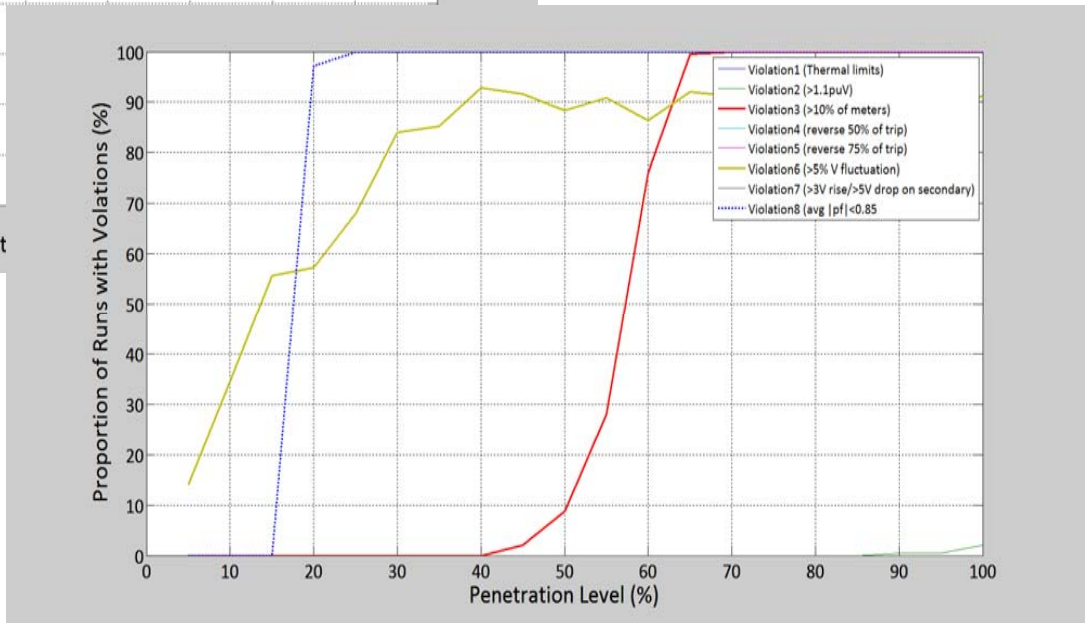
Table 4.1 - Circuit Operational Limits and Thresholds For determining Native Limits		
Violation #	**Violation**	**Violation Description**
1	Thermal Overloads	Limit: Exceeding any device thermal limit, 100% rating (200% for secondary service transformers)
2	High Instant Voltage	Limit: Any instantaneous voltage over 1.10 p.u. at any point in the system.
3	5 min ANSI Violation	Limit: ANSI C84.1: 0.95>V>1.05 p.u. for 5 minutes at >10% of meters in the system.
4	Moderate Reverse Power	Warning: Any reverse power that exceeds 50% of the minimum trip setting of the substation breaker or a recloser. (Requires analysis of protection coordination)
5	High Reverse Power	Limit: Any reverse power that exceeds 75% of the minimum trip setting of the substation breaker or a recloser.
6	Voltage Flicker	Limit: any voltage change at a PV point of common coupling that is greater than 5% between two one-minute simulation time-steps. (Adapted from the Voltage fluctuation design limits, May 1994)
7	Voltage Drop/Rise on Secondary	Limit: 3V drop or 5V rise across the secondary distribution system (Defined as the high side of the service transformer to the customer meter)
8	Low Average PF	Warning: Average circuit power factor <0.85 (Measured at substation)
9	Circuit Plan Loading Limit	Warning: Nameplate solar exceeds 10MVA for a 12 kV circuit, 13 MVA for a 16 kV circuit, or 32 MVA for a 33 kV circuit.
10	High Short Circuit Contribution	Warning: Total short circuit contribution from downstream generation not to exceed 87.5% of substation circuit breaker rating

Native Limit Curves - Results

Circuit 11



Circuit 19

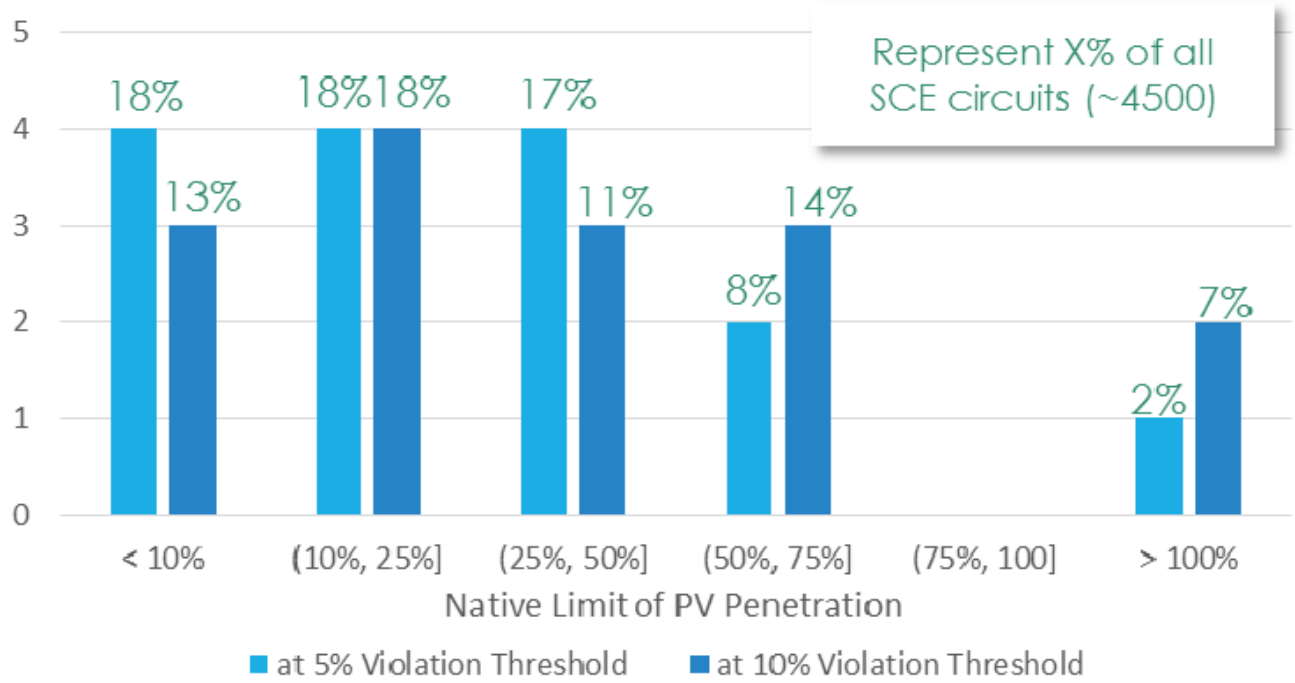


For each circuit, 4,000 time-series simulations are conducted. The results of these simulations are distilled into a single plot for each feeder.

Native Limits of SCE circuits -Results

42% to 53% of SCE circuits are limited to 50% PV penetration or less.

Figure 4.1: Histogram of Native Limits for 15 Circuits



- *This is based on the uniform distributed PV adoption model used specifically in this study*
- *Based on the 15 most representative feeders (which represent a total of 63% of SCE circuits)*

Mitigation Strategies

Both traditional and non-traditional technologies and strategies were investigated for reaching 100% PV penetration on the representative circuit models

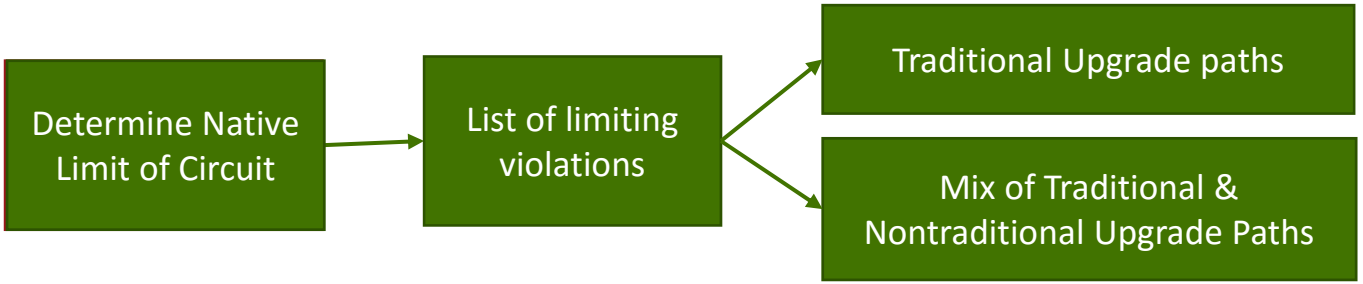


Table 5.1 - Summary of Mitigation Types and Strategies

Traditional Upgrade Strategies		Non-Traditional Mitigation Strategies	
T1	Adjustment of existing shunt capacitor set points	NT1	Fixed power factor on solar inverters
T2	Removal of existing shunt capacitors	NT2	Advanced Controls on PV Inverters
T3	Addition of shunt capacitors	NT3	Centratlized Energy Storage (utiltity)
T4	Installation of voltage regulators (regulating their output voltage magnitude)	NT4	Commercial Behind Meter Energy Storage
T5	Reconductoring of a primary line/cable segment		
T6	Reconductoring of a secondary line/cable segment		
T7	Upgrade of secondary service transformer		

Demand Response was considered but not viable based on results.

Mitigation Examples: Circuit #11

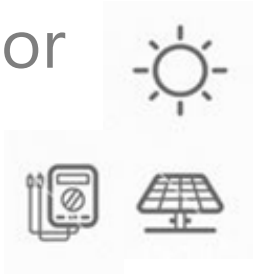
Traditionally can fix low Power Factor with capacitors. However, using central and/or decentralized energy storage units can also help, as well as help peak shaving.

Nonetheless, in order to be cost effective, energy storage must be part of a multi-objective control strategy.

Circuit #11	at X% PV	Limiting Violations	Traditional Mitigation:
	15%	Low Average PF	→ Added two new substation capacitors One 600 kvar (Fixed) One 600 kvar (VAR controlled) → Reduced the size of one existing downstream capacitor (600 kvar to 300 kvar)
	The non-traditional mitigation upgrade path to address these violations:		
	Path 1 15%	→ Central energy storage unit in Target pf 0.98, +/- 1050 kvar	
	Path 2: 15%	→ 11 decentralized storage units in peak shaving control Six Large Units, 250 kW/1,000 kWh {Charge on=-55 kW Charge off=-50 kW Discharge on=500 kW Discharge off=300kW} Five small units, 100 kW/ 50 kWh {Charge on=-0.5 kW Charge off=0 kW Discharge on=5 kW Discharge off=0kW}	

Mitigation Examples: Circuit #19

Solar can cause voltage flicker and power factor issues. Using advanced solar inverter controls can alleviate these issues.



	at X% PV	Limiting Violations	Traditional Mitigation:
Circuit #19	5%	Voltage Flicker	
	15%	Low Average PF	→ Added two substation Capacitors One 150 kVAR (Fixed) One 150 Kkvar (VAR controlled)
	45%	5 min ANSI Violation	→ Added one substaion regulator controlling output voltage to 2,380V
	The non-traditional mitigation upgrade path to address these violations:		
	0%	→ Fixed power factor control with 0.95 leading	

For Circuit #19, the flicker seen at 5% was actually due to capacitor switching, so it did not pose a limit to PV.

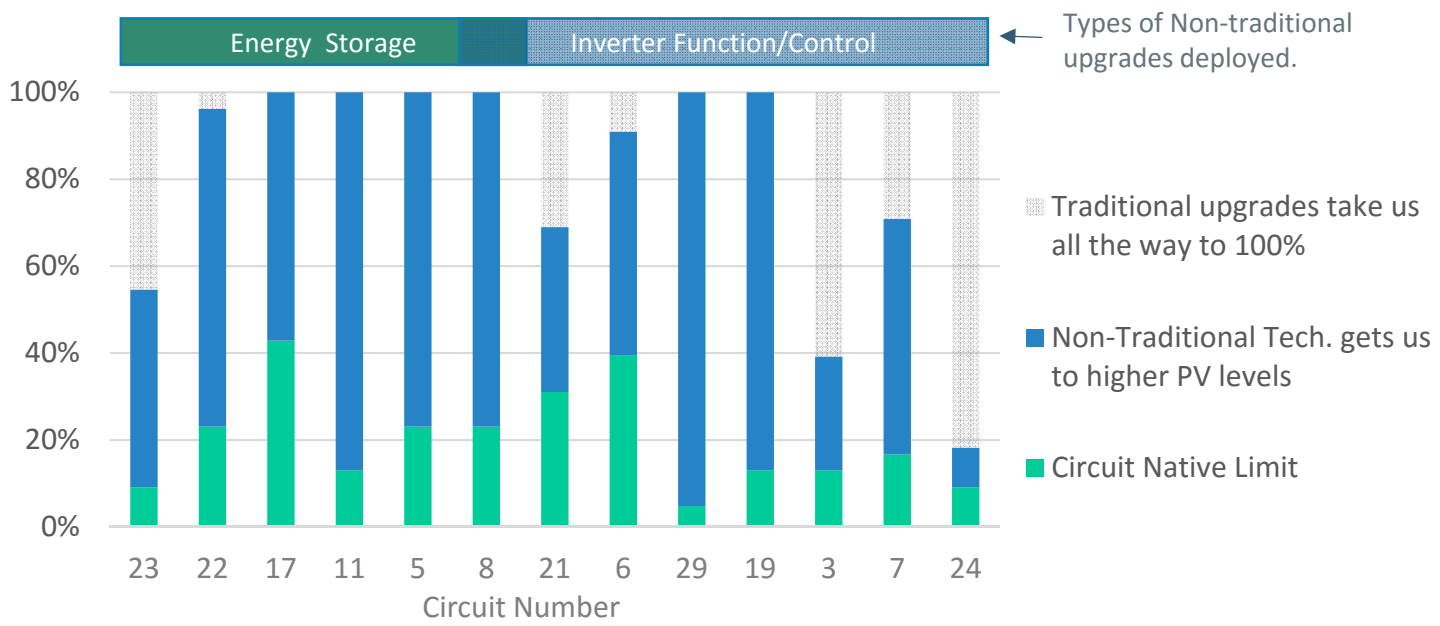
Results of Mitigation Paths

Table 5.1 Mapping of Mitigation Technologies to Operating Violations

Violation → / Mitigation ↓	1. Thermal Overloads	2. High Instant Voltage	3. 5 min ANSI Violation	4. Moderate Reverse Power	5. High Reverse Power	6. Voltage Flicker	7. Voltage Drop/Rise on Secondary	8. Low Average PF	9. Circuit Plan Loading Limit	10. High Short Circuit Contribution		
Shunt Capacitors			X					X				
Voltage Regulator		X	X									
Reconductor (primary)	X											
Reconductor (secondary)	X					X	X					
Upgrade Transformer	X					X	X					
Inverter (fixed pf)		X	X					X				
Inverter (Volt-VAR)		X	X					X				
Storage (central)	X							X				
Storage (distributed)	X											

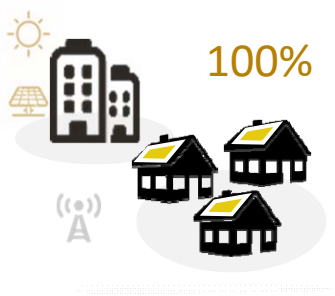
Overcome the limits

Traditional upgrades alone can reach 100% PV penetration. Emerging technologies can help surpass native limits, but may still require traditional upgrades.



** This is based on the uniform distributed PV adoption model used specifically in this study*

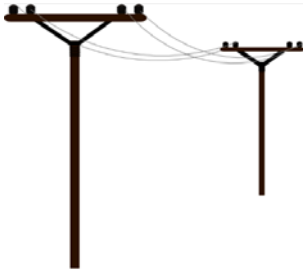
Key Lessons Learned



All 15 circuits can support 100% penetration of PV once the proper mitigation strategies have been applied.

Nearly 50% of SCE circuits can host less than 50% PV, where approx. 40% can host less than 25% PV

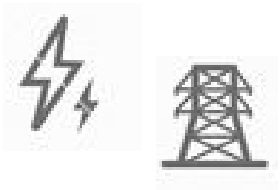
Determining how to achieve 100% penetration on legacy circuits can be challenging, with a mitigation leading to new violations. (domino effect)



The most common violations experienced were power factor and voltage based.

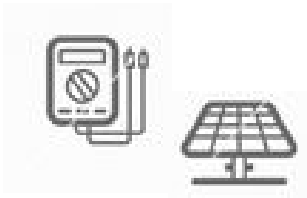
Proper sizing of secondary drops when new solar is installed is essential.

Key Lessons Learned Cont'd



Controlling circuit voltage and circuit power factor simultaneously with capacitors is not practical at high penetrations of PV.

Energy storage is a technically viable solution for power factor, but may not be cost effective unless it is part of a larger multi-objective control strategy.



Inverter-based Volt-VAR is not able to address low lagging power factor and high voltages at the same time. However, Volt-VAR combined with other traditional upgrades can be highly effective.

10 min break – Q&A

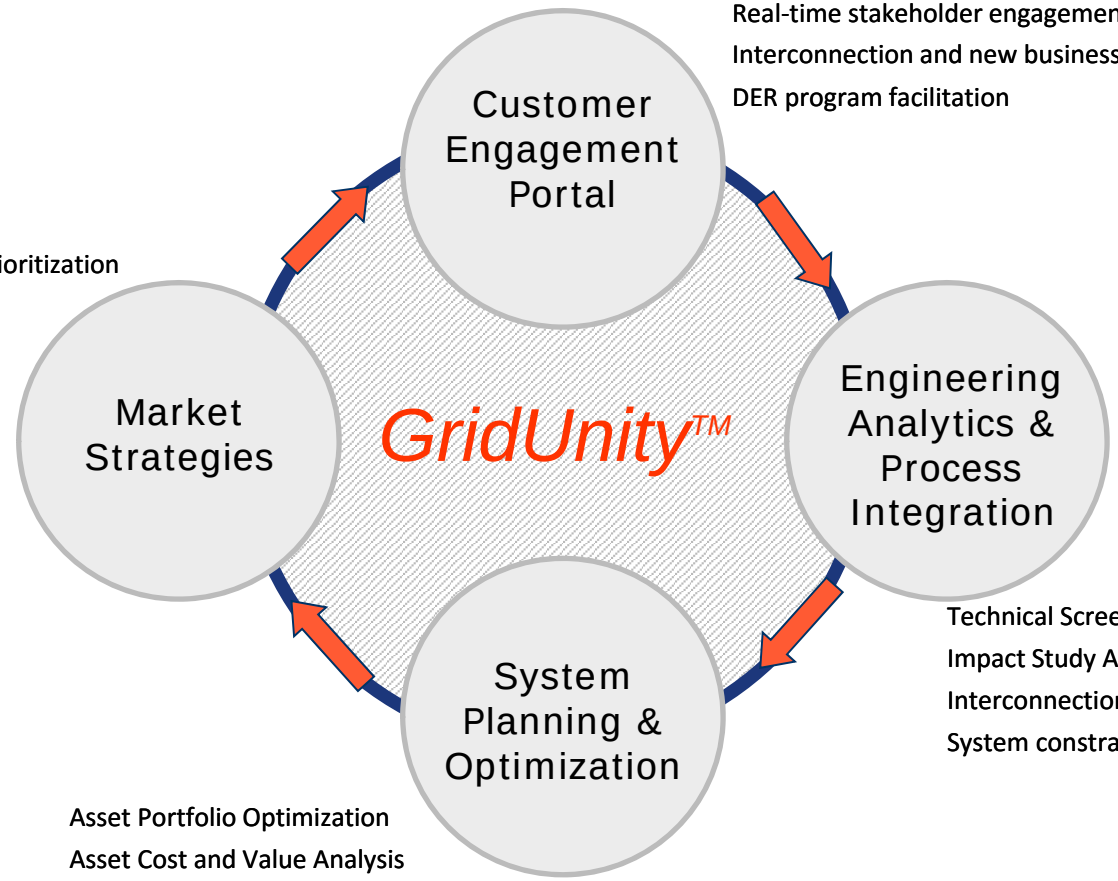
GridUnity Demo

Cloud Platform by

Alex Dinkel, Brian Fitzsimons

GridUnity™ Platform

Cloud based High performance computing & advanced analytics for utilities



Real-time stakeholder engagement
Interconnection and new business process
DER program facilitation

System forecasting
Regulatory Alignment
Capital Deployment Prioritization

Technical Screening
Impact Study Analysis
Interconnection Cost Analysis
System constraint identification

Asset Portfolio Optimization
Asset Cost and Value Analysis
Hosting Capacity & Optimal Asset Placement

Breaking down organizational silos ….

The GridUnity Revolution

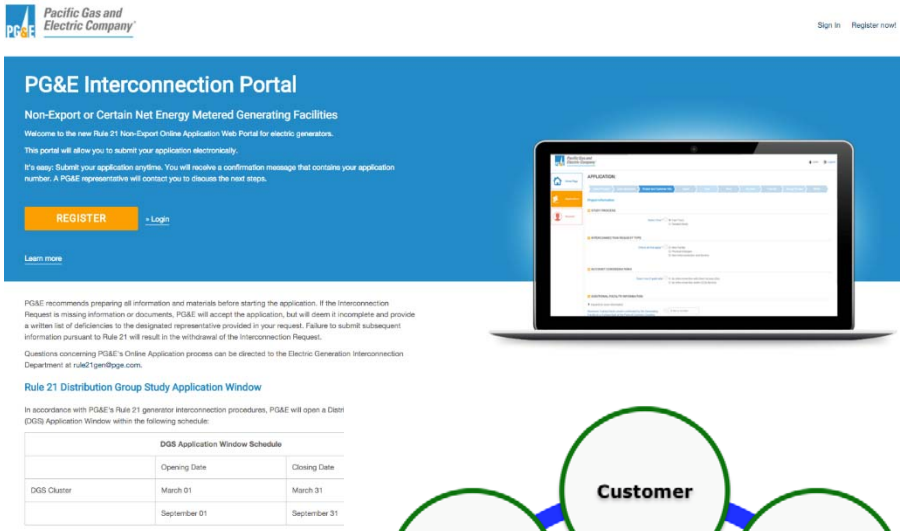
Folding time and improving quality allows utilities to transform their relationship with all stakeholders

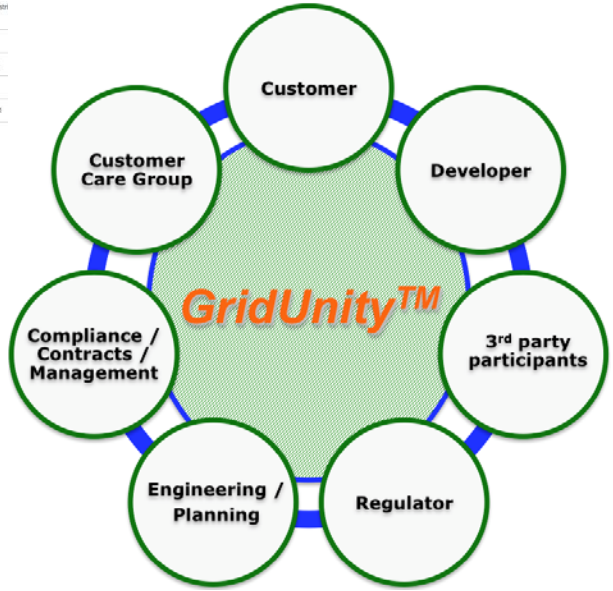
Interconnection Application Process		
Utility Requirement	*Old Systems*	***Qado GridUnity***
Application Submittal & Review	5-10 days	**30 minutes**
Technical Screening	4-8 hours	**10 seconds**
Supplemental Screening	5 days	**3-5 minutes**
Impact Study (CESIR)	55 days	**60 minutes**
Permission to Operate	5-10 days	**3 seconds**

Distribution System Planning and Asset Strategy	
Type of Analysis	*Benefits*
Predictive DER growth forecasting	Pro-active System Management
Circuit hosting capacity analysis	System ability to meet RPS goals
Circuit optimization analysis	Increase efficiency and reliability
DER placement analysis	Provide certainty for DER developers

GridUnity™ Customer Application Portal

DER, Load, Storage… all new programs

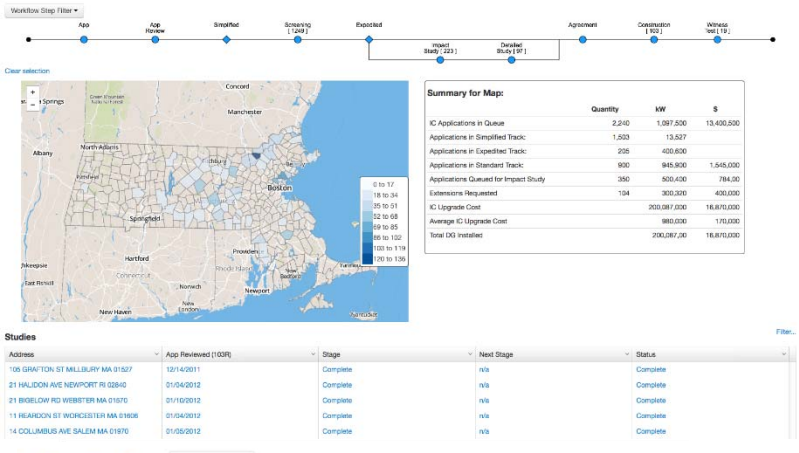




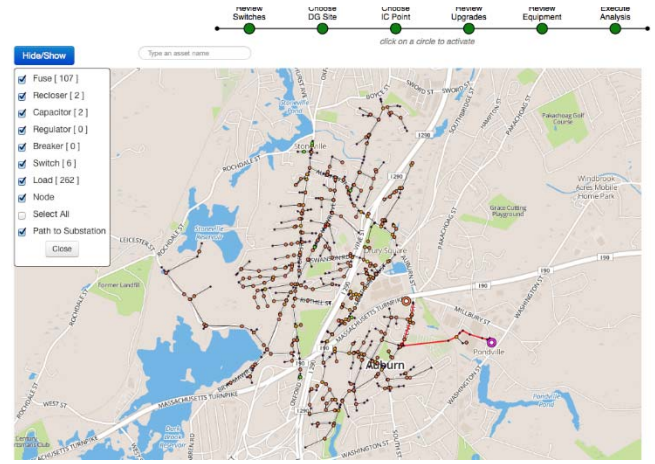
- One entry point for all customer programs, activities & reporting
- Offers Socratic program guidance
  - Interconnection Applications
  - New Business Applications
  - Modification of Service requests
- Real-time customer updates
- Reduces customer & utility errors
- Supports a complete paperless process for applications, payments, agreement execution and permission to operate
- Maintains a complete digital history of all party actions
- Provides end-to-end monitoring, measuring and reporting of stakeholder actions

GridUnity DER Technical Screening & Impact Studies
Customizable dashboards simplify decision making

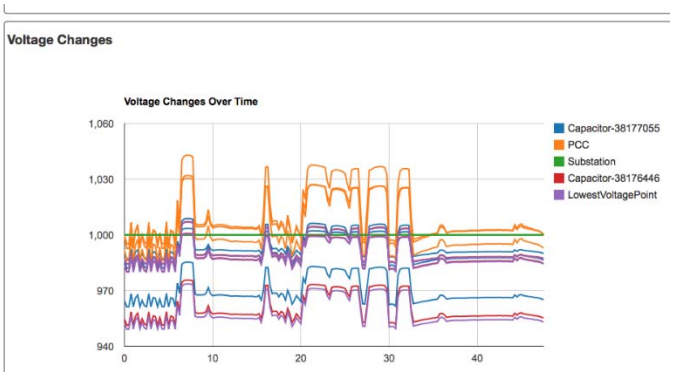
Data Standardization: holistic view of data



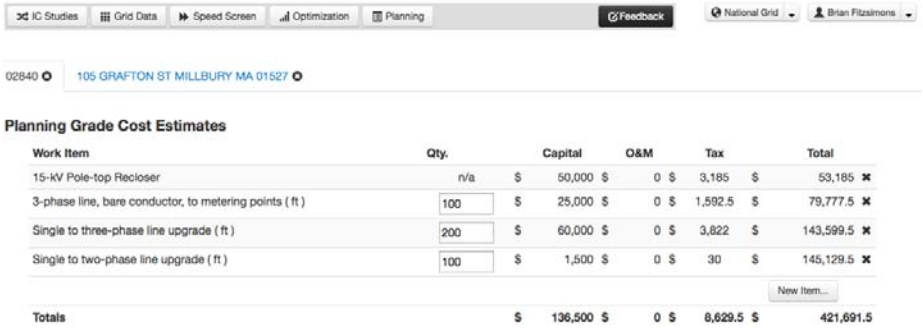
Distribution system visualization: simplify decision making



Time series: analyze multiple systems simultaneously



Real-time cost association: support optimized decisions

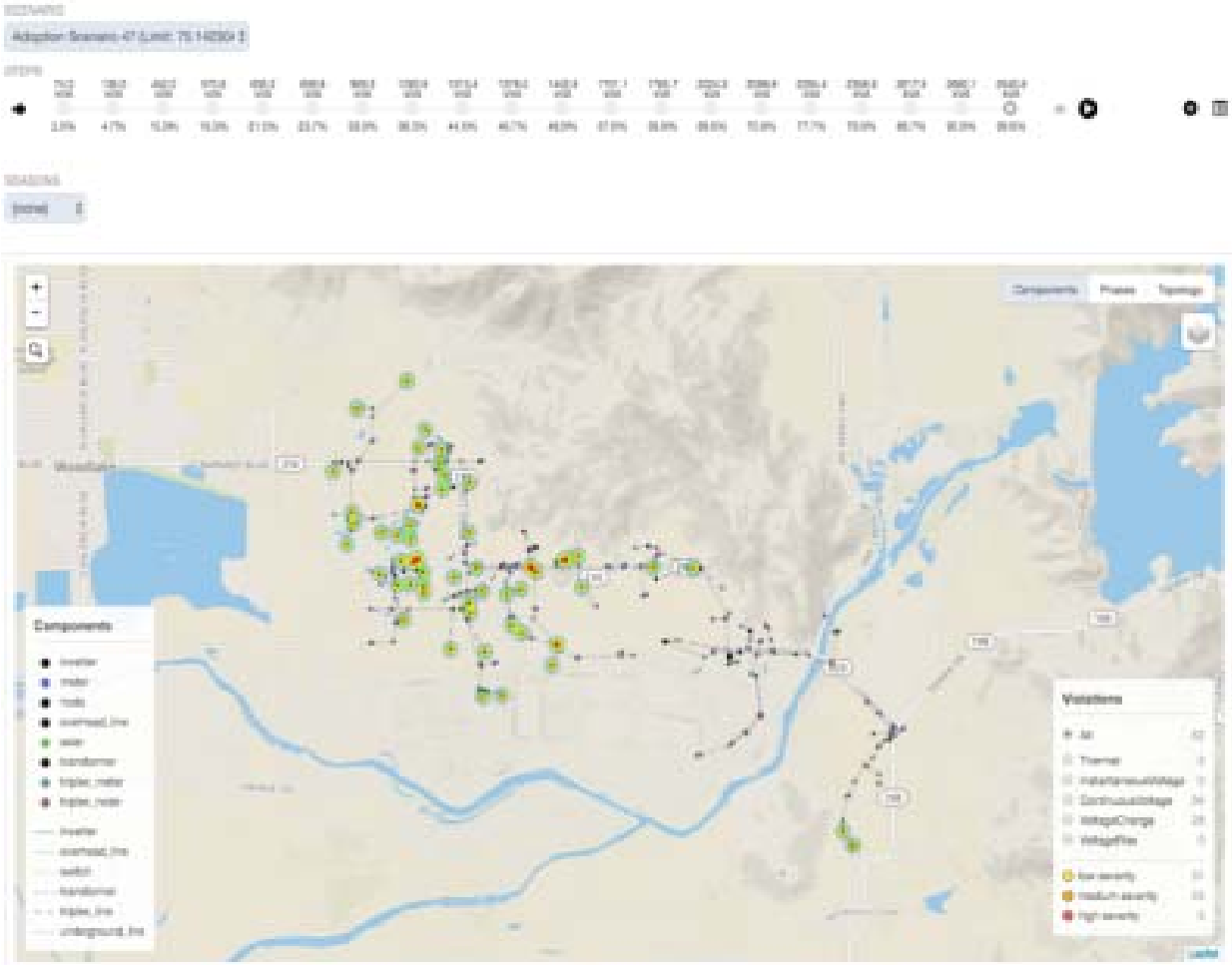


GridUnity Distribution Grid Optimization

Forecasting | Future Case Simulation | Mitigation | Simulation and Cost Comparison

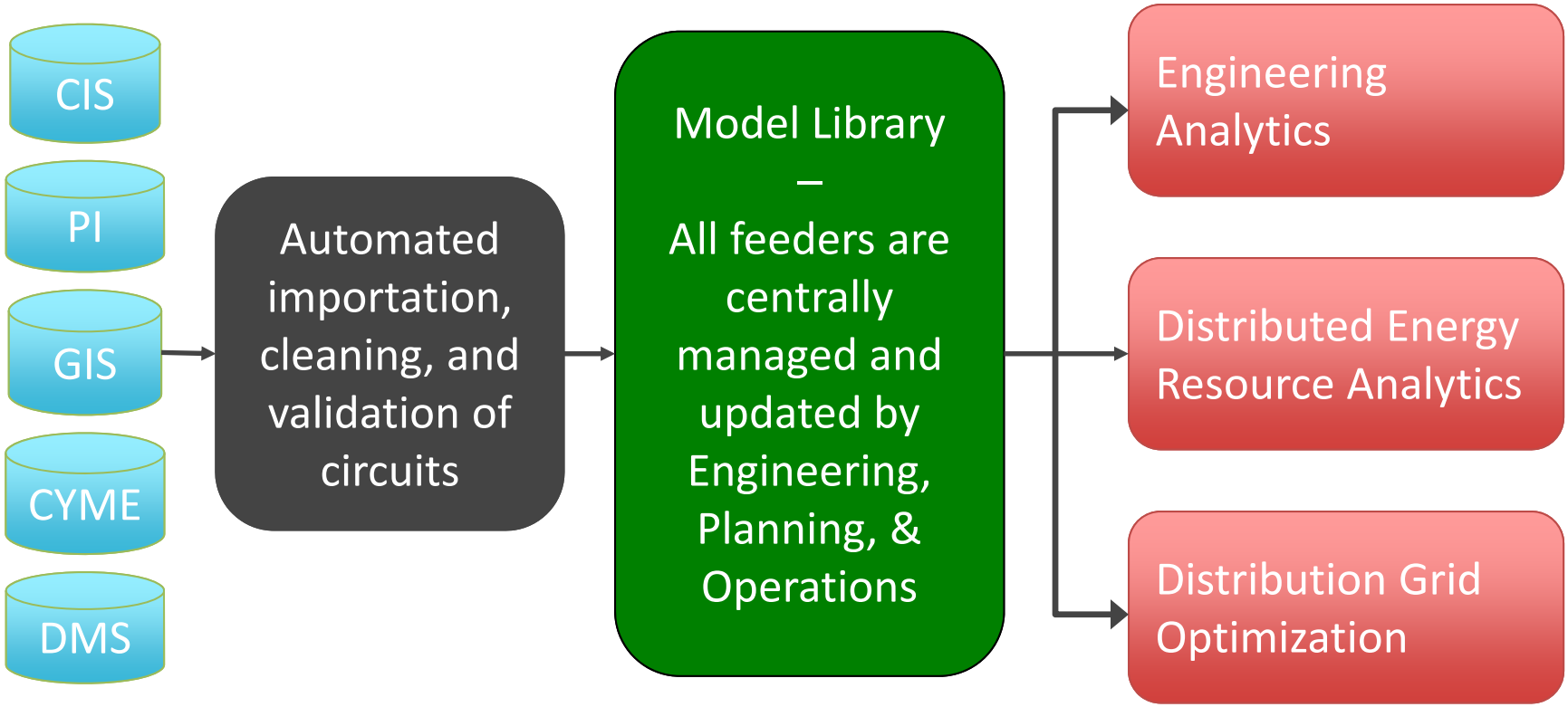
Hosting Capacity Analysis

- Hosting Capacity: is the penetration level at which a feeder experiences violations without upgrades
- - PV adoption driven stochastic future case scenarios
- - 1 minute time series simulations used to assess impact criteria at various penetration levels
- - violation criteria include voltage limits, thermal overloads, voltage variability, feeder power factor etc..



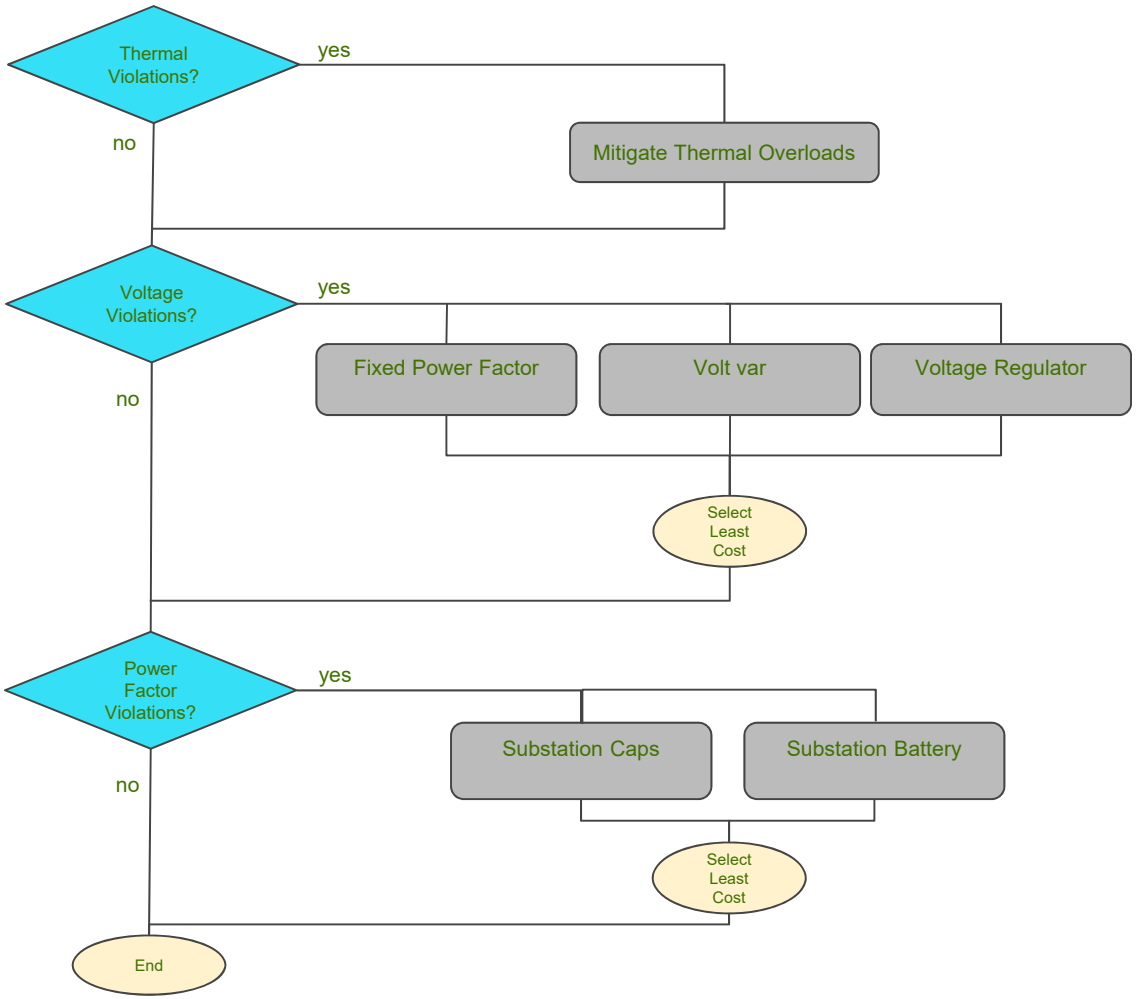
GridUnity Distribution System Model Lifecycle

Feeder models are centrally managed and continuously updated, providing asset health, capital investment prioritization, risk management as a natural outcome



Mitigation and Cost Analysis

- The automated mitigation process follows the rules the utility has established within GridUnity.
- As the PV penetration limits are hit the system violations are recorded.
- GridUnity analyzes the limitations and runs through various simulations to determine the appropriate mitigation.
- Once the mitigation has been defined the costs for the mitigation and calculated from the cost table the utility has uploaded into GridUnity

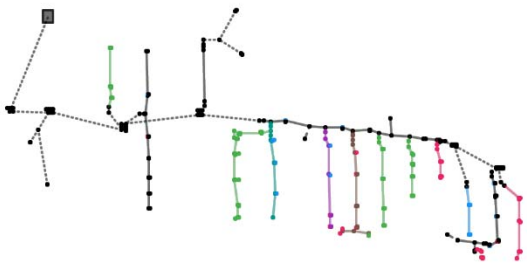


Software Demonstration

Generalized Methodology Results

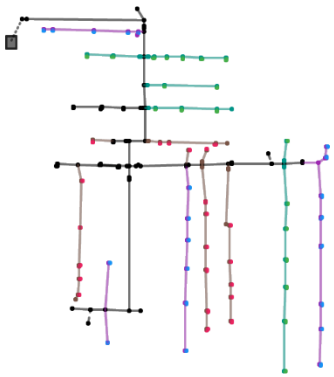
How well do representative circuit native limits predict native limits of actual circuits?

circuits with similar designs have similar results



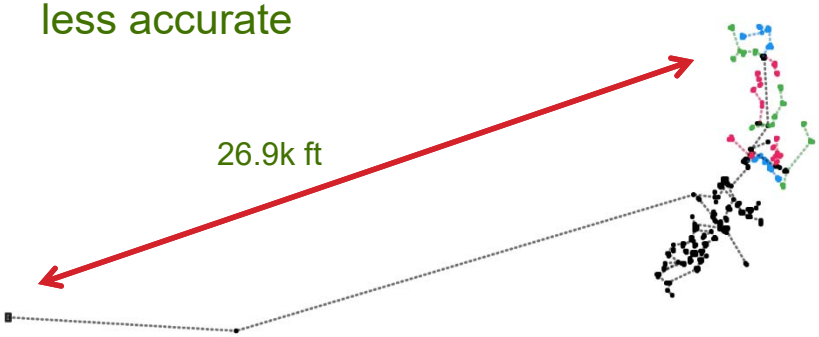
Representative Circuit 21: 30-70%

≈



Actual Circuit A: 20-60%

Circuits with different shapes, conductor sizes, and/or load distributions are less accurate



Representative Circuit 7: 50-90%

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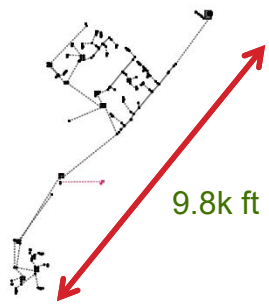
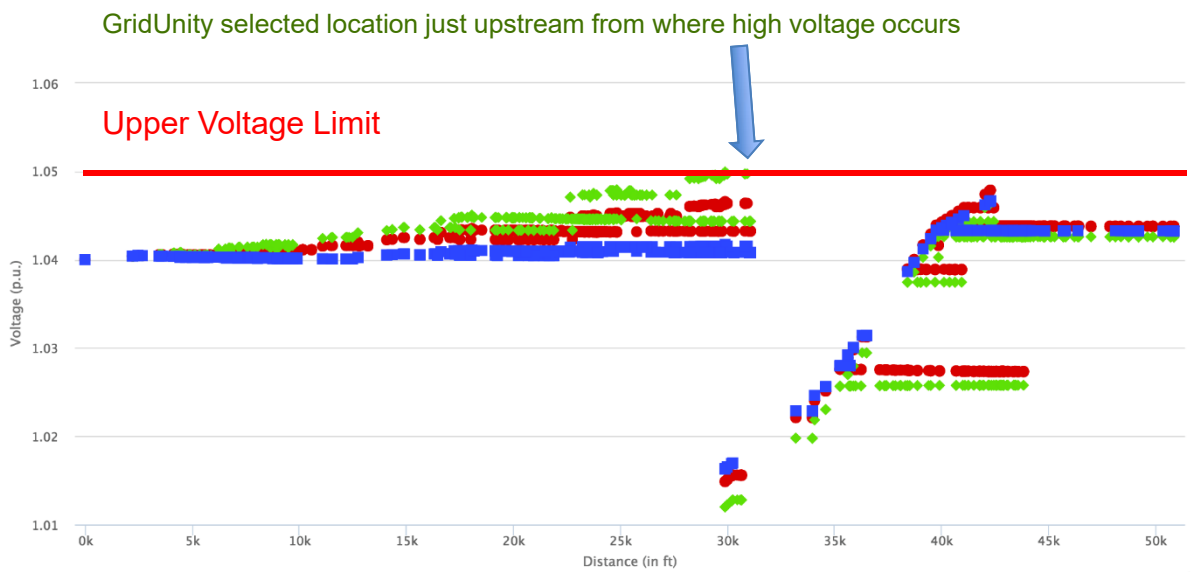


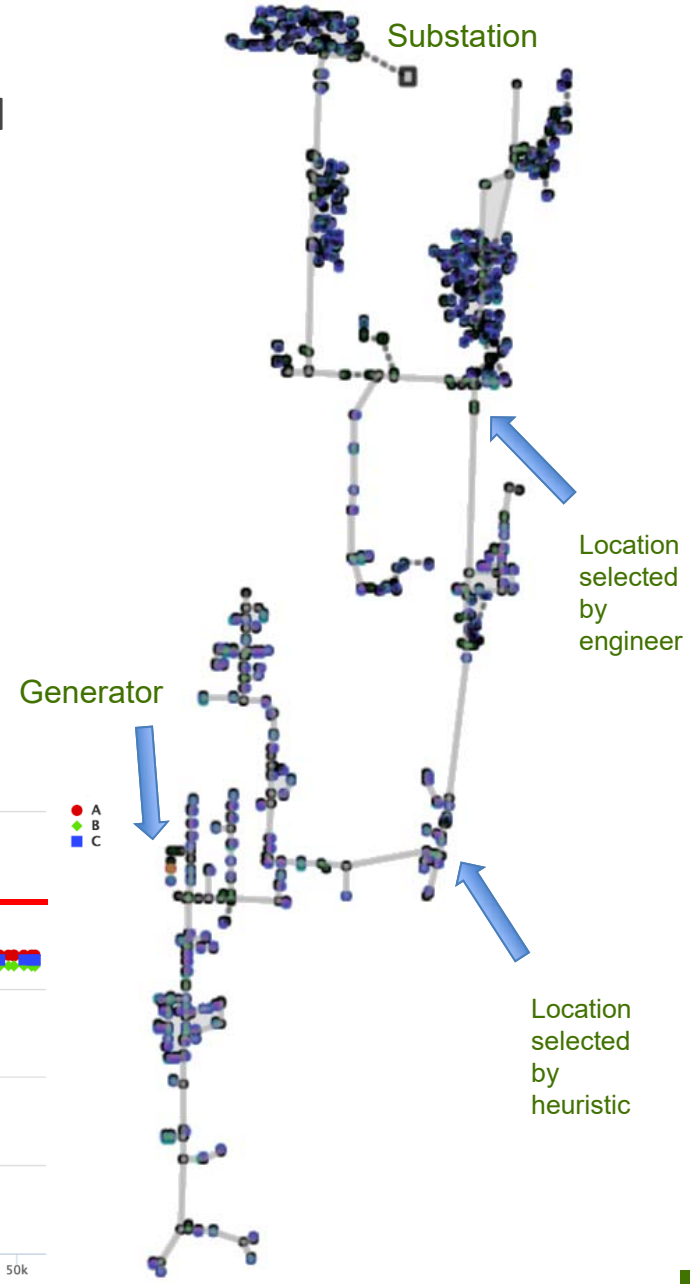
Actual Circuit C: 200-225%

Operational Feeders

How do automated mitigation results compare to manual study results?

- Example: 1.25 MW PV interconnection request. Voltage regulator required to mitigate high voltage when impact study performed by engineer
- GridUnity selected a location on the feeder by analyzing the daytime minimum load timepoint voltage profile
- Both locations successfully mitigate violations





Benefits to Rate Payers

- Provide utilities insight into how to proactively develop cost effective mitigation strategies incorporating non-traditional technologies and better plan for the high PV penetration future

- Inform on-going grid modernization efforts and DRP demonstrations which target increased penetration of DERs and understanding value of these resources

Benefits to Rate Payers

- QADO tool can help look at different situations for understanding the cost impact to plan proactively for PV penetration
- Increase understanding of the issues associated with high solar PV penetration and improve quality of interconnection applications

Thank You!

Questions?

Appendix

Insert extra slides with extra details here

Thank You!

The draft final report is available for download at:
http://www.calsolarresearch.ca.gov/

Questions?

Mitigation Results Summary

exercise to analyze data:

circuit	# of paths	NL	new limit	type	notes
3	1	15%	30%	inverter PF	mixed with traditional after new limit
5	2	30%	100%	ES central, inverter PF	only non-traditional
6	1	65%	85%	inverter PF	mixed with traditional after new limit
7	2	20%	65%	inverter PF, inverter VV	mixed with traditional after new limit
8	1	30%	100%	ES VAR control	only non-traditional
11	2	15%	100%	ES central, ES decentral	only non-traditional
17	2	75%	100%	ES central VAR. ES decentral	only non-traditional
19	1	15%	100%	inverter PF	only non-traditional
21	2	45%	45%,55%	PF	mixed with traditional after new limit
22	1	30%	95%	ES central VAR	mixed with traditional after new limit
23	1	10%	50%	ES central VAR	mixed with traditional after new limit
24	1	10%	10%	inverter VV	mixed with traditional after new limit
29	1	5%	100%	inverter PF	only non-traditional

2 cases adding inverter control didn't increase NL, still needed traditional upgrades

7 cases, non-traditional paths needed some traditional upgrade

6 some cases, non-traditional paths worked alone