Screening Distribution Feeders: Alternatives to the 15% Rule

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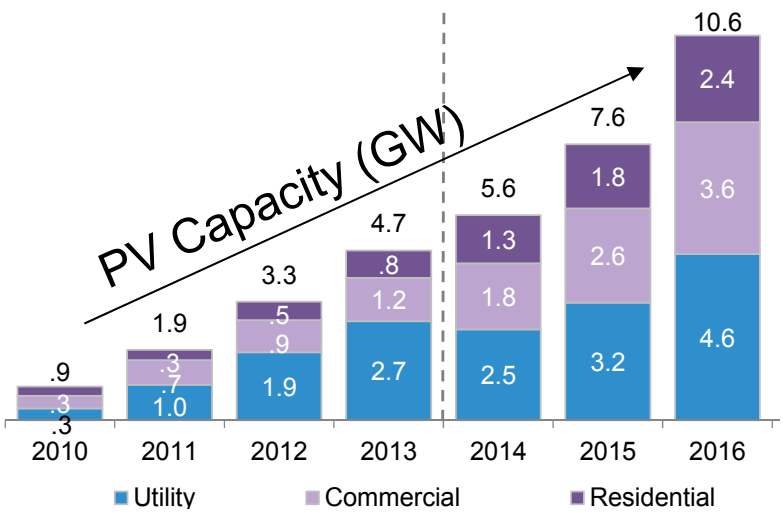
Project Description

Industry Challenge

- Landscape is changing
  - 155,000 US installations in 2013
  - 94% connected to distribution
  - Expected to triple by 2016
- New Challenges for Utilities
  - **Accommodate more PV**
  - **Expedite interconnection process**

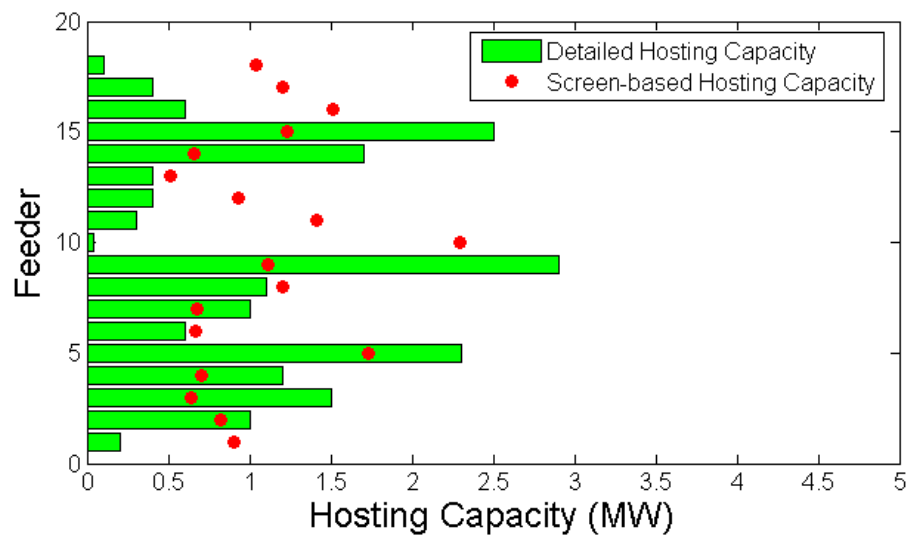


Project Goal

- Improve current screening
  - Efficiently evaluate new interconnection requests
  - Take into account existing PV and feeder-specific factors

Current Screening

Under and over conservative results



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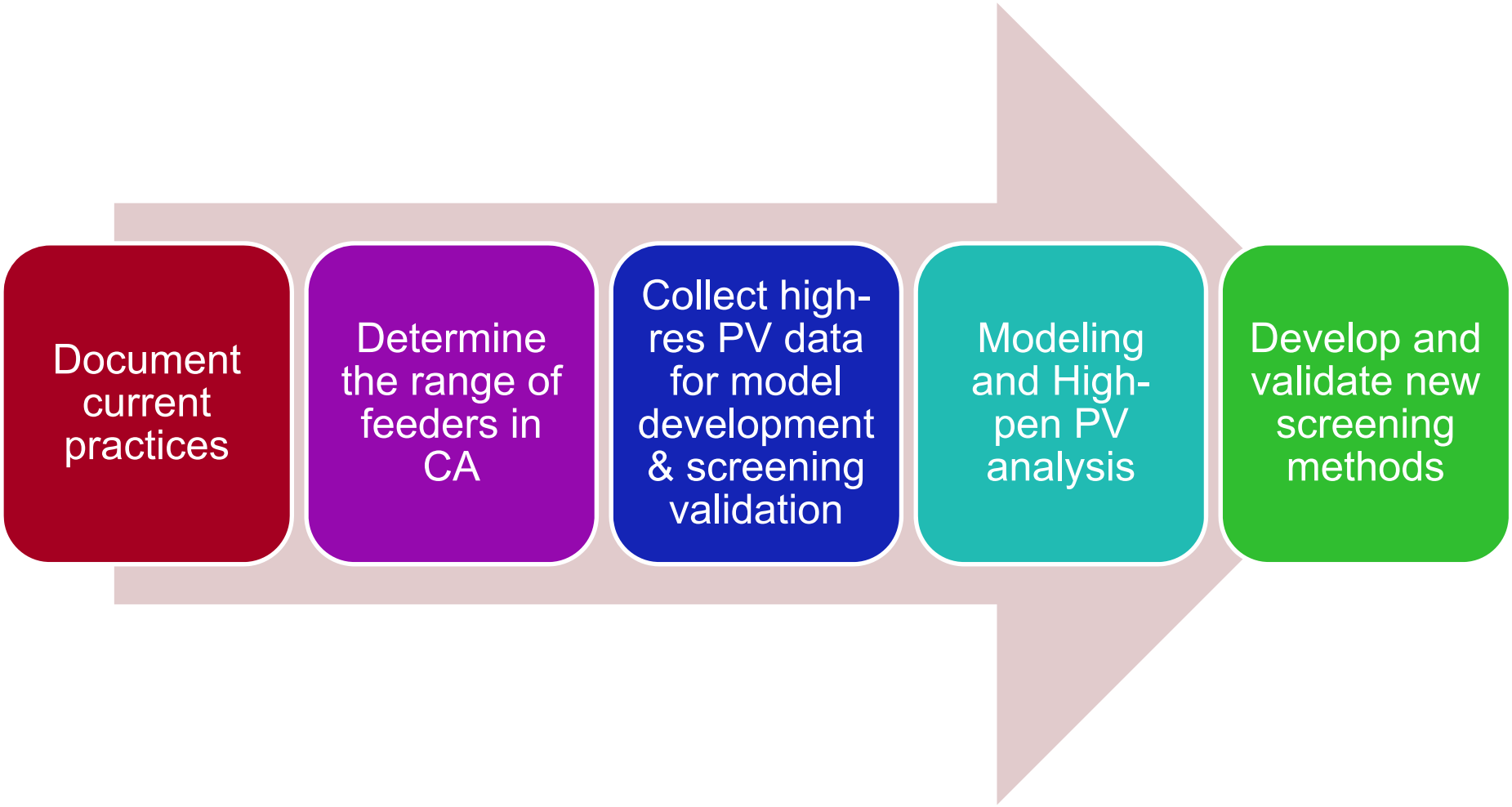
Approach to Develop Alternative Screening Methods



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Webinar Agenda

- Project Tasks
  - Current Screening Practices
  - Clustering Distribution Feeders
  - Solar Monitoring
  - Feeder Modeling and Detailed Analysis
  - Suggested and Validated Screen Modifications
- Distribution Resource Plans
- Conclusions

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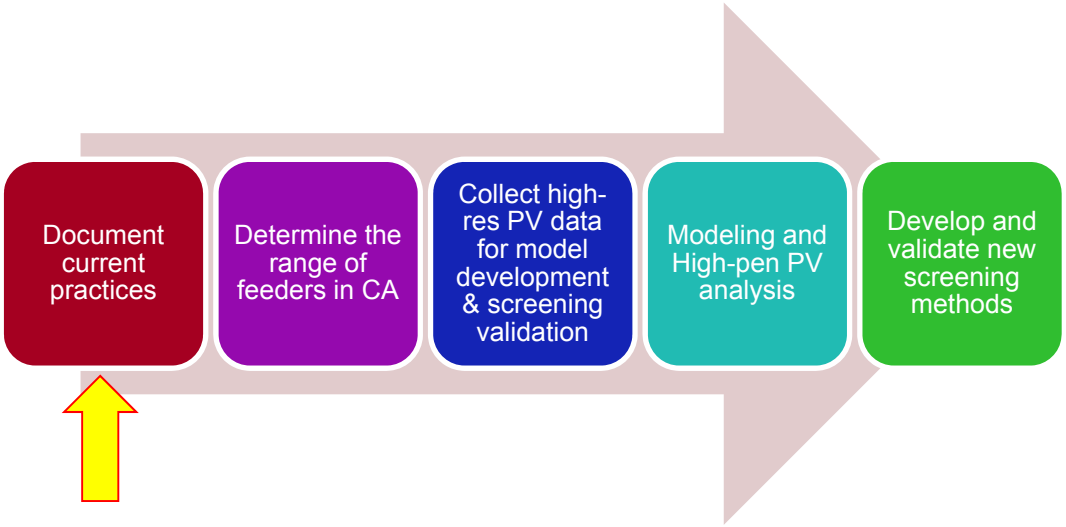
Project Task: Methods for Screening Distribution Feeders



Current Utility Screening Practices, Technical Tools, Impact Studies, and Mitigation Strategies for Interconnecting PV on the Electric Distribution Systems. EPRI, Palo Alto, CA: 2014. 3002003277.

- Task Purpose
  - Investigate and document current practices for screening PV interconnection requests among California utilities and from other sources outside California
- Approach
  - Consider federal, state, and local interconnection procedures pertaining to CA (Rule 21, WDAT, SGIP)
  - Consider non-CA and European utility screening practices as well

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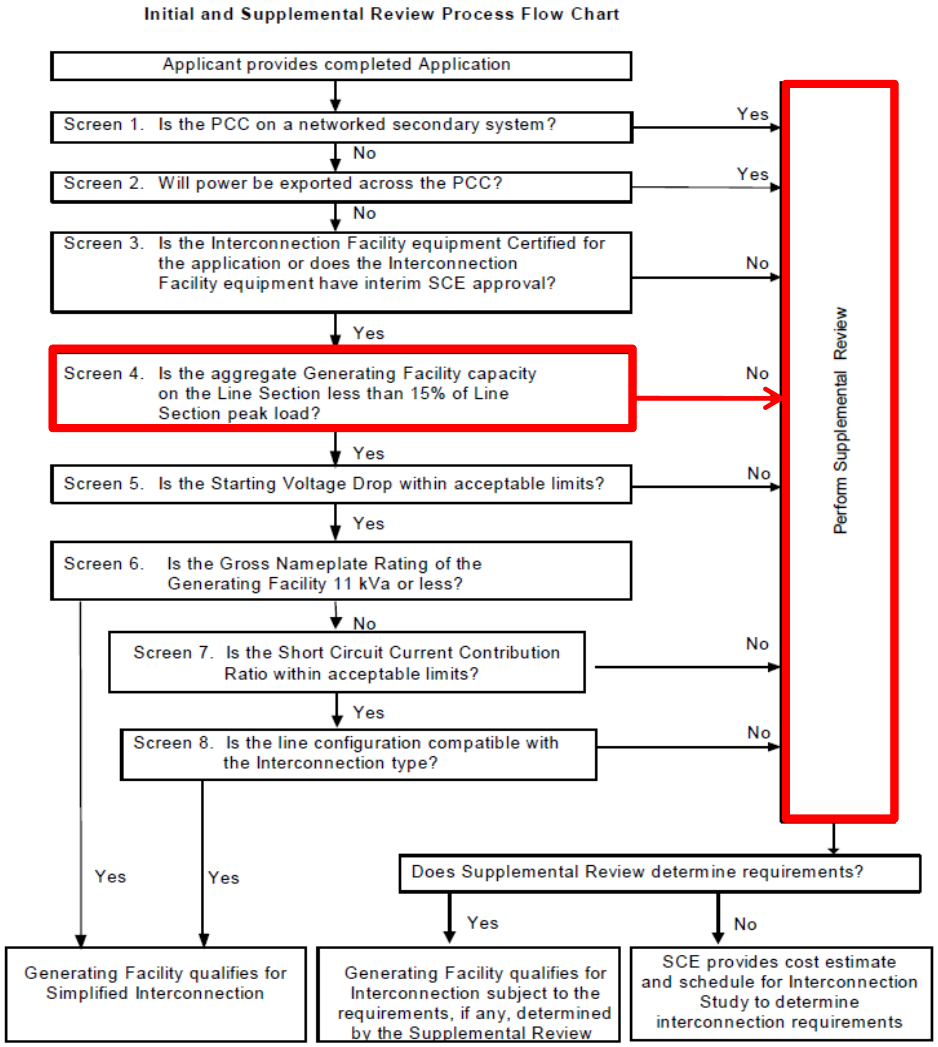
Review of Utility Interconnection Screens

CPUC Rule 21 Initial Review Screens

1. Not a secondary network
2. Not exporting across PCC
3. Certified equipment
4. <15% of peak load on line section
5. Starting voltage drop within limits
6. <=11 kVA nameplate rating

   If > 11 kVA rating …
7. Nameplate and short circuit contribution ratio within limits
8. Compatible transformer connection

If project passes all screens, interconnection agreement approved



Source: SCE Rule 21 – Generating Facility Interconnections, August 2004

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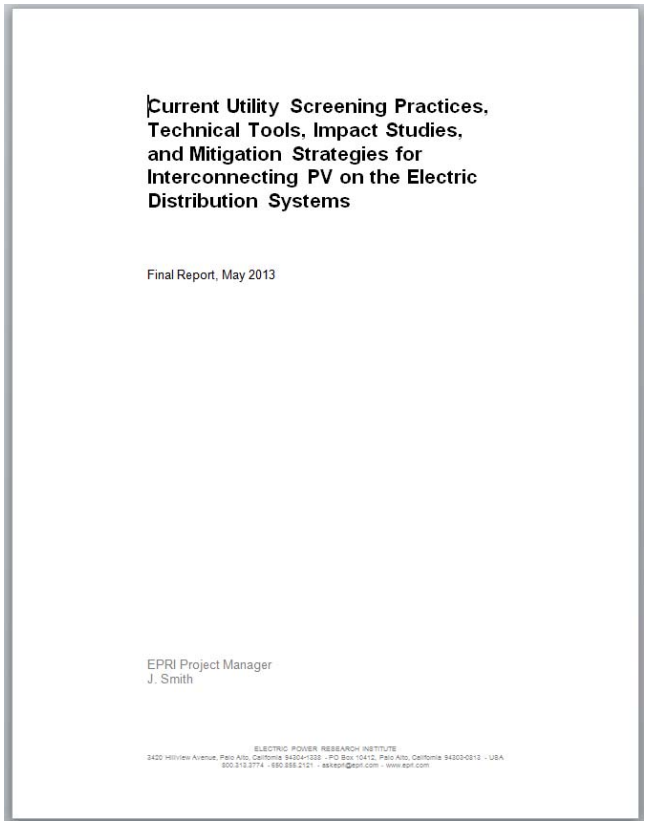
Utility Survey of Current Practices



Current Utility Screening Practices, Technical Tools, Impact Studies, and Mitigation Strategies for Interconnecting PV on the Electric Distribution Systems

Final Report, May 2013

EPRI Project Manager
J. Smith

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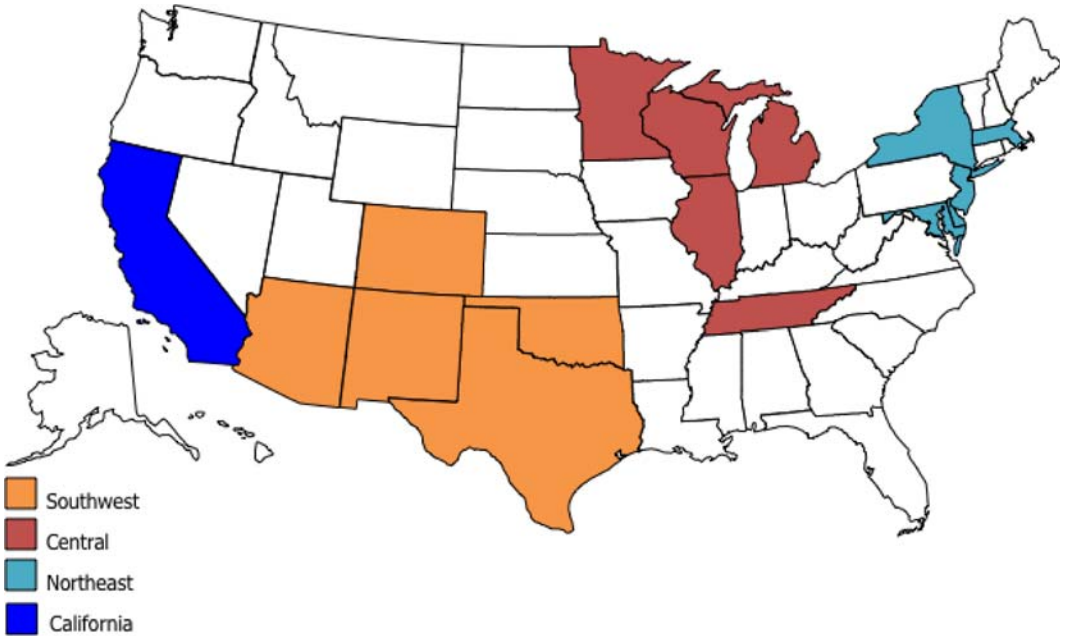

- Survey included input from 19 utilities operating in four regions of the United States, California (4), Southwest, Central and Northeast

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Common Practices Include:

- Online applications, guidelines
- Low-cost/no-cost application
- Uniform state rules for all utilities (e.g. Rule 21)
- Standard approach to evaluating applications
- Supplemental screening options
- Standardized distribution modeling platform
- Emphasis on good communication with applicant
- Online tracking system
- Standard impact studies (when required)

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Specific Survey Responses: PV Penetration

The technical screen "fast track advisory limits" are 2 MW for 12 kV circuits, and 3 MW for 21 kV circuits.

The rule of thumb within the engineering departments has been a maximum of 10 MW of DG on any feeder.

Circuits rated at 12 kV and 16 kV are allowed to have a maximum of 450 Amps of generation, which is about 10 MW on the 12 kV circuits and 13.5 MW on the 16 kV circuits.

We use 100% of minimum daytime load or 30% of the daytime peak load as a penetration parameter, rather than 15% of peak 24/7 load, for PV system screening.

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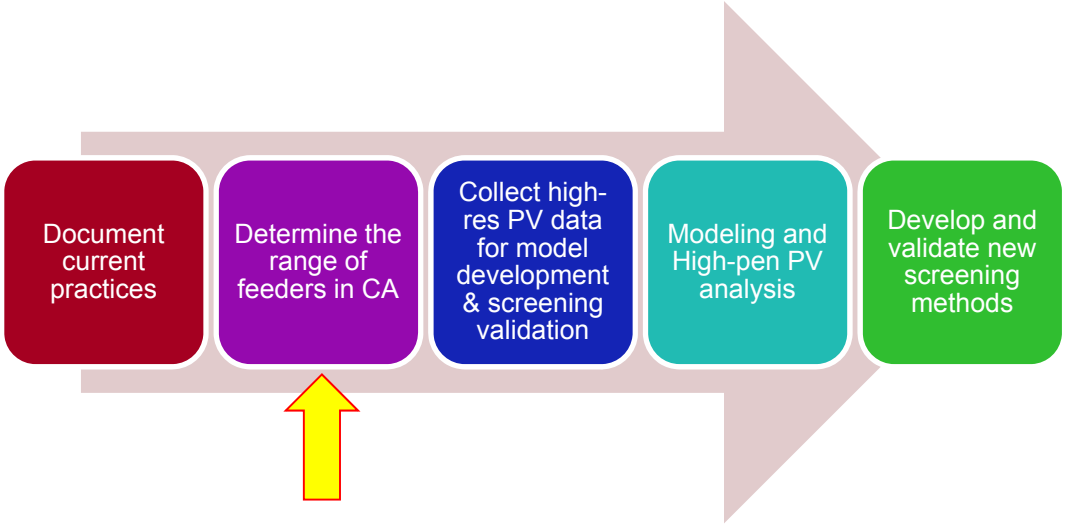
Project Task: Clustering Distribution Feeders



Clustering Methods and Feeder Selection for PV System Impact Analysis. Palo Alto, CA: 2014. 3002002562.

- Task Purpose
  - Determine a set of representative feeders to be used for detailed analysis
- Approach
  - Characterize over 8,163 distribution feeders
  - Use a clustering method to group feeders by their characteristics
  - Representative feeders then chosen from the clusters

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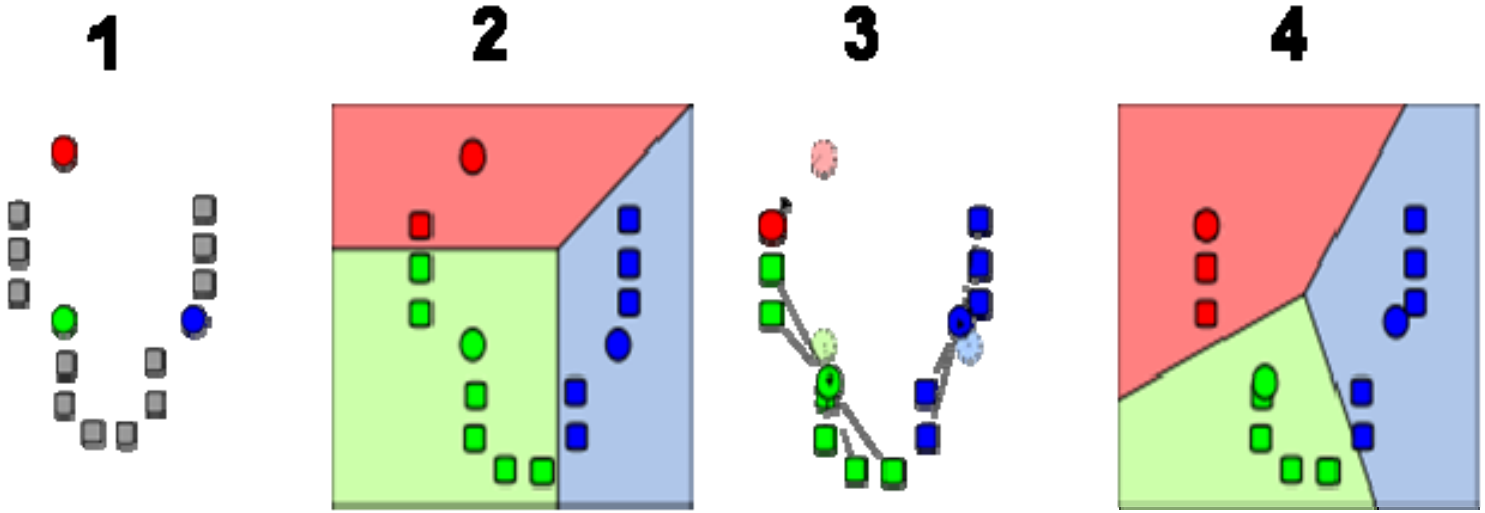
What is Clustering?



Example of K-means partitional algorithm. Source: Wikimedia Commons

1) *K=3* initial "means" are randomly generated within the data domain (shown in color)
2) *k* clusters are created by associating every observation with the nearest mean
3) The centroid of each of the *k* clusters becomes the new mean
4) Steps 2 and 3 are repeated until convergence has been reached

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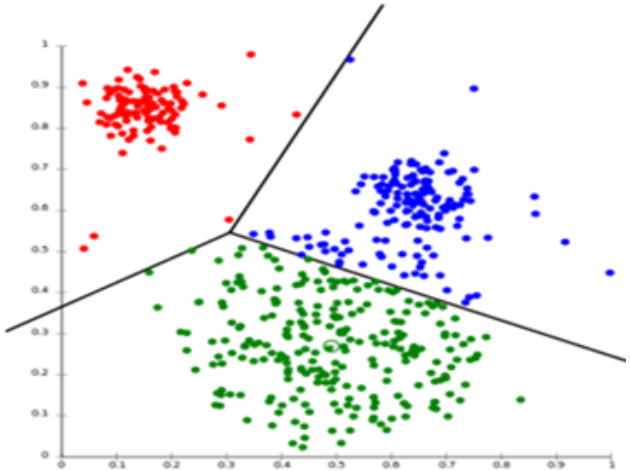
Purpose of Clustering

- Purpose
  - Determine groups of feeders with similar characteristics using K-Means Clustering to better understand how variation in feeder characteristics affects hosting capacity
  - Select representative feeders to use for development of the screening methodology and for validating the screening methodology
- Steps
  1. Initial Data Review and Cleanup
  2. **Selecting Variables for Clustering**
  3. Removing Outliers
  4. **Selecting the Number of Clusters**
  5. **Feeder Selection**



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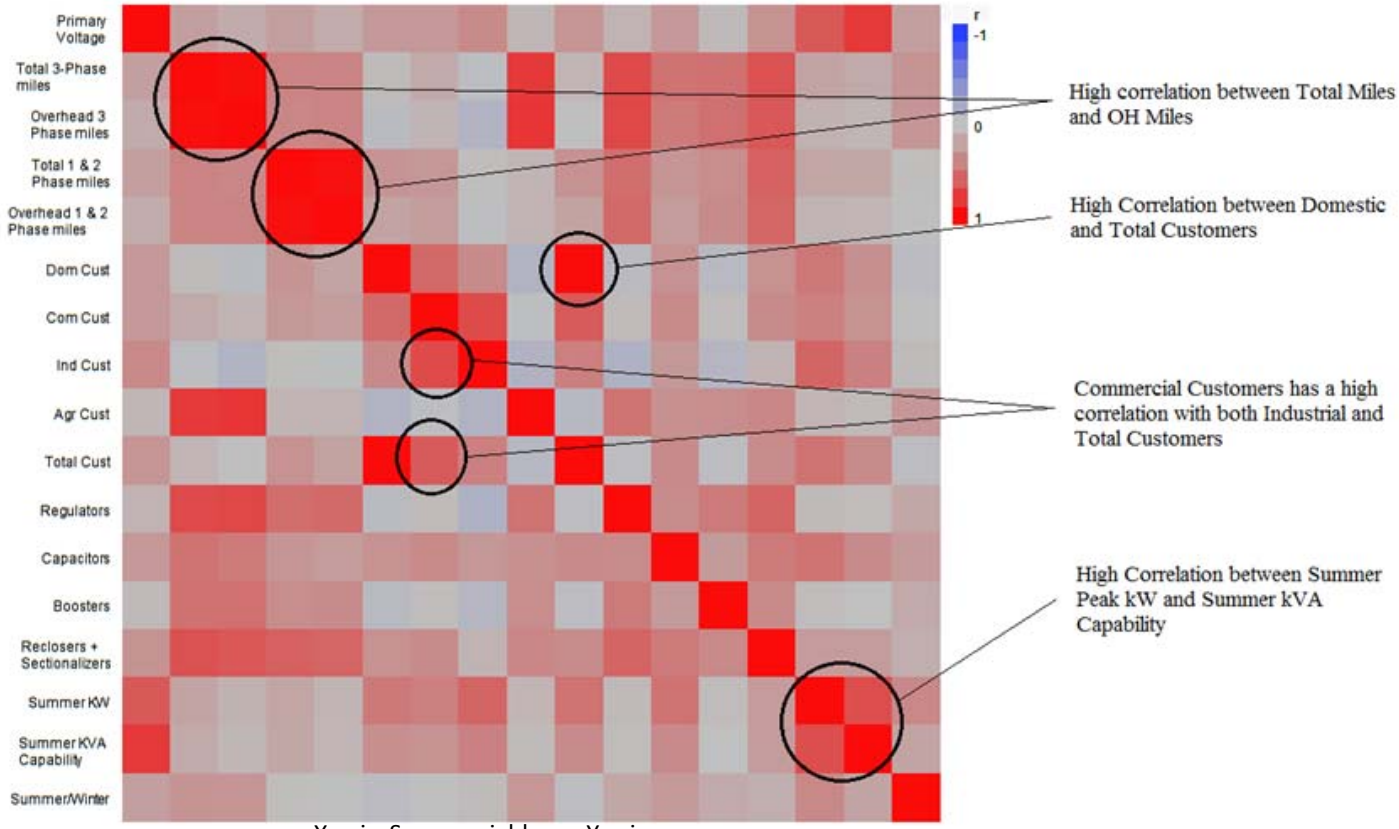
Overview of Clustering Approach



X-axis: Same variables as Y axis

2. Selecting Variables for Clustering

- Initial variables were selected based on their potential impact on differentiating feeder types and on DG hosting capacity
- Pairs of highly correlated variables were examined using heat maps to determine if it was appropriate to remove one or more variables

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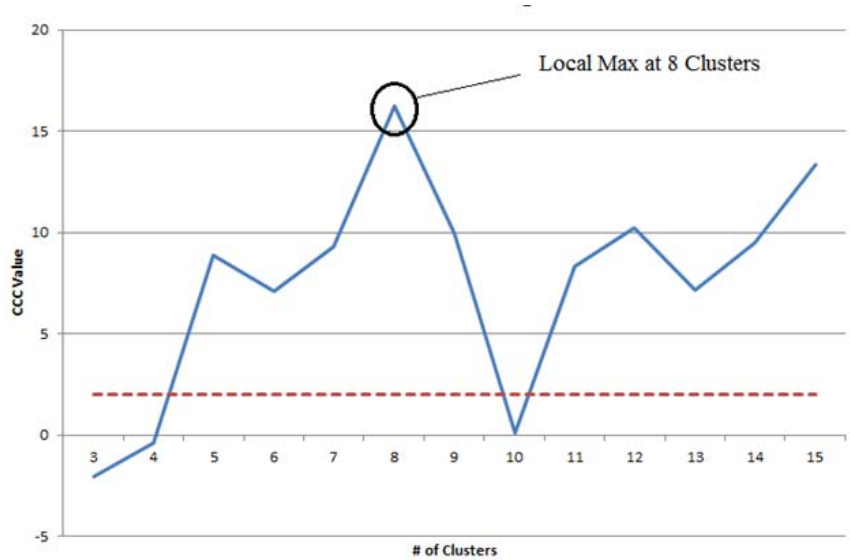
Overview of Clustering Approach

4. Selecting the Number of Clusters

- K-means algorithms require the number of clusters to be specified in advance
- The optimum number of clusters can be derived from a Cubic Clustering Criterion (CCC) which is a quality metric based on minimizing the within-cluster sum of squares.
  - A local maximum that rises above 2 and drops below 2 is an indication of an optimal number of clusters
- Resulting clusters were reviewed and redundant clusters were eliminated to help minimize the number of representative feeders for each utility given the project objectives and limitations



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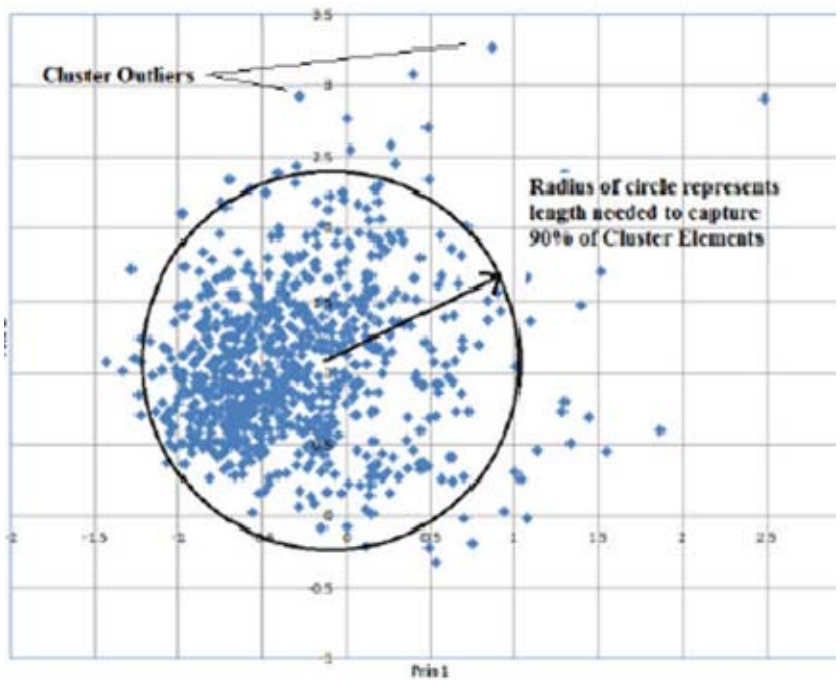
Overview of Clustering Approach

5. Feeder Selection

- Using Principle Component Analysis (PCA), the feeder closest to the center mean of the cluster was selected, and is therefore highly representative of the cluster
- Other important parameters used to make final feeder selection included significant PV system presence and the existence of feeder SCADA data
  - These parameters are critical for developing the accurate feeder models needed for analysis



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Clustering Results

- Twenty-two feeders selected from the three utilities
  - 16 feeders for detailed analysis and development of the screening methodology
  - 6 feeders for validation of the methodology
- A relatively small number of initial clusters are needed to represent the variation in the feeder characteristics for each utility
- Characteristics that were primary drivers of cluster selection include:
  - Voltage class
  - Feeder length
  - Number of voltage regulators

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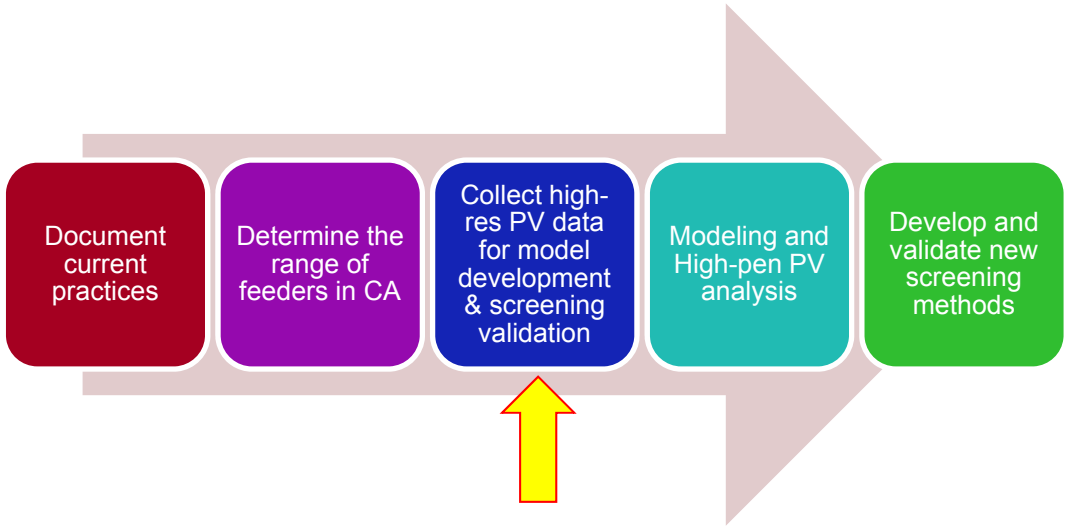
Project Task: Collect Solar Measurement Data



http://calsolarresearch.ca.gov/funded-projects/88-screening-distribution-feeders-alternatives-to-the-15-rule

- Task Purpose
  - Collect solar measurement data for modeling and to understand variability
- Approach
  - Pole-mount units capture time-series measurements of actual PV output
  - Accounts for the spatial relationships of measurement locations as well as the time synchronization of PV power into the grid

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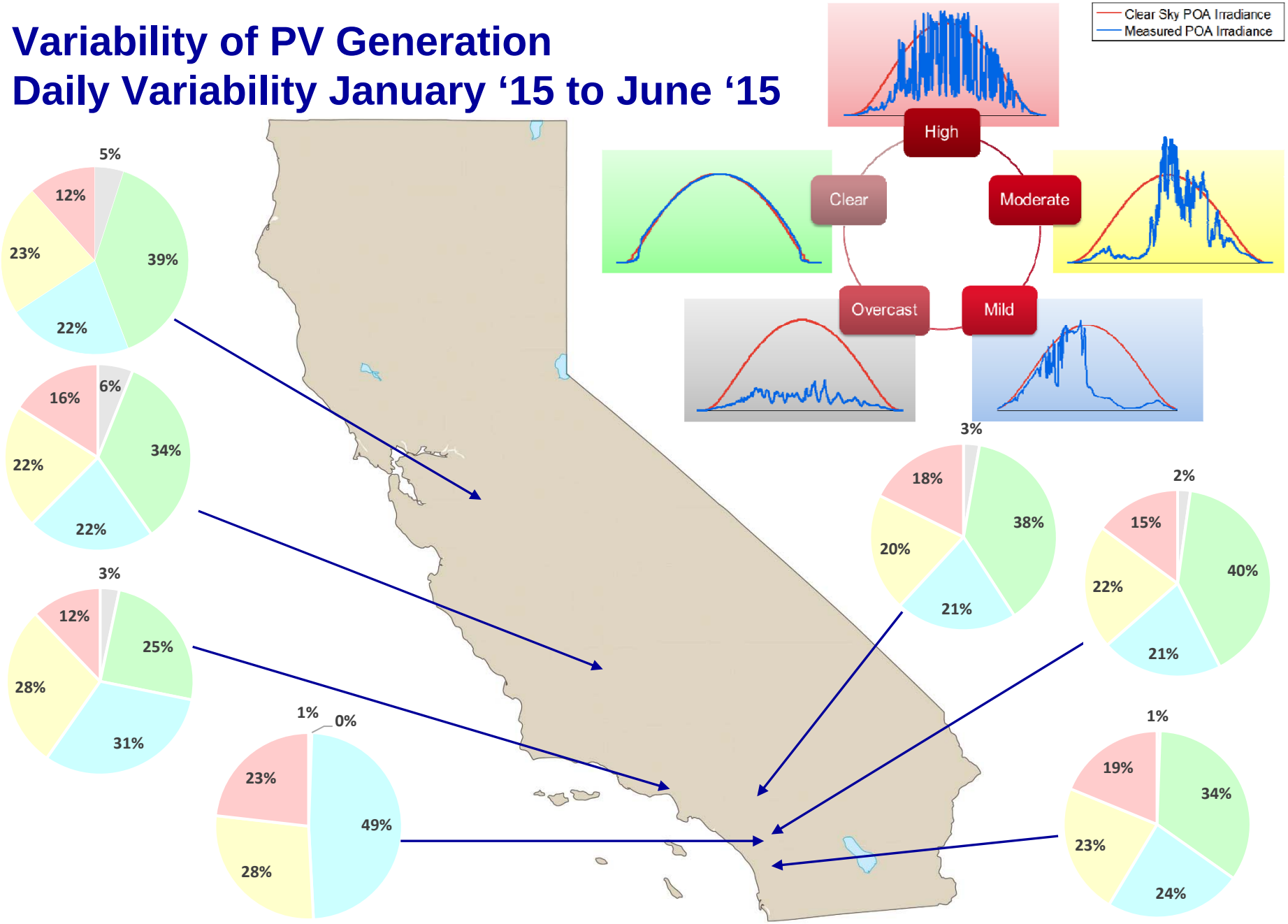
Variability of PV Generation
Daily Variability January '15 to June '15



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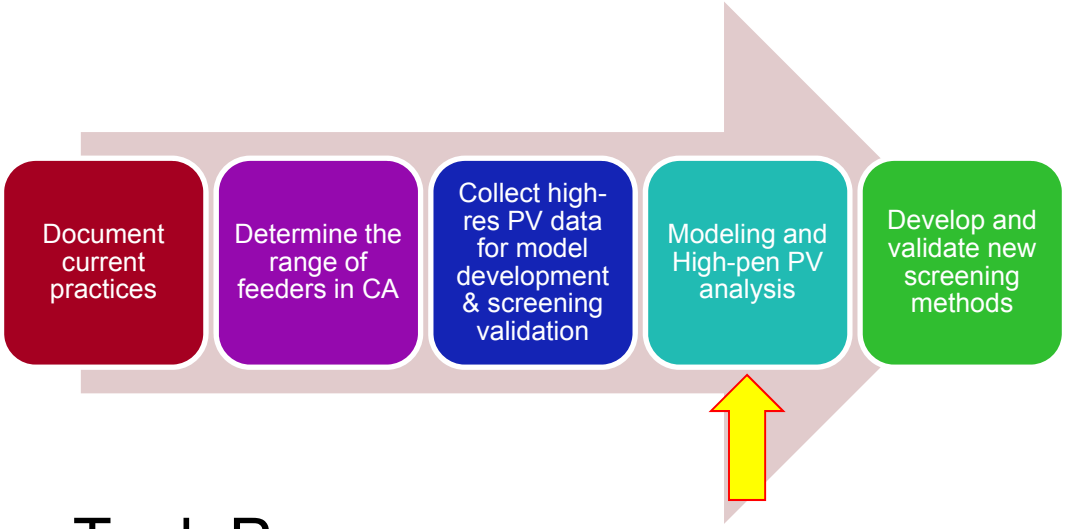
Project Task: Modeling and PV Impact Analysis



Alternatives to the 15% Rule: Modeling and Hosting Capacity Analysis of 16 Feeders. EPRI, Palo Alto, CA: 2015. 3002005812.

- Task Purpose
  - Perform high-penetration PV assessment of the 16 feeders to determine each specific feeder's hosting capacity for solar PV
- Approach
  - Create detailed models of the representative feeders
  - Utilize EPRI's Distributed PV (DPV) Feeder Analysis Method for determining feeder impacts and hosting capacity
  - Simulate a wide range of PV deployment scenarios and penetration levels on each feeder

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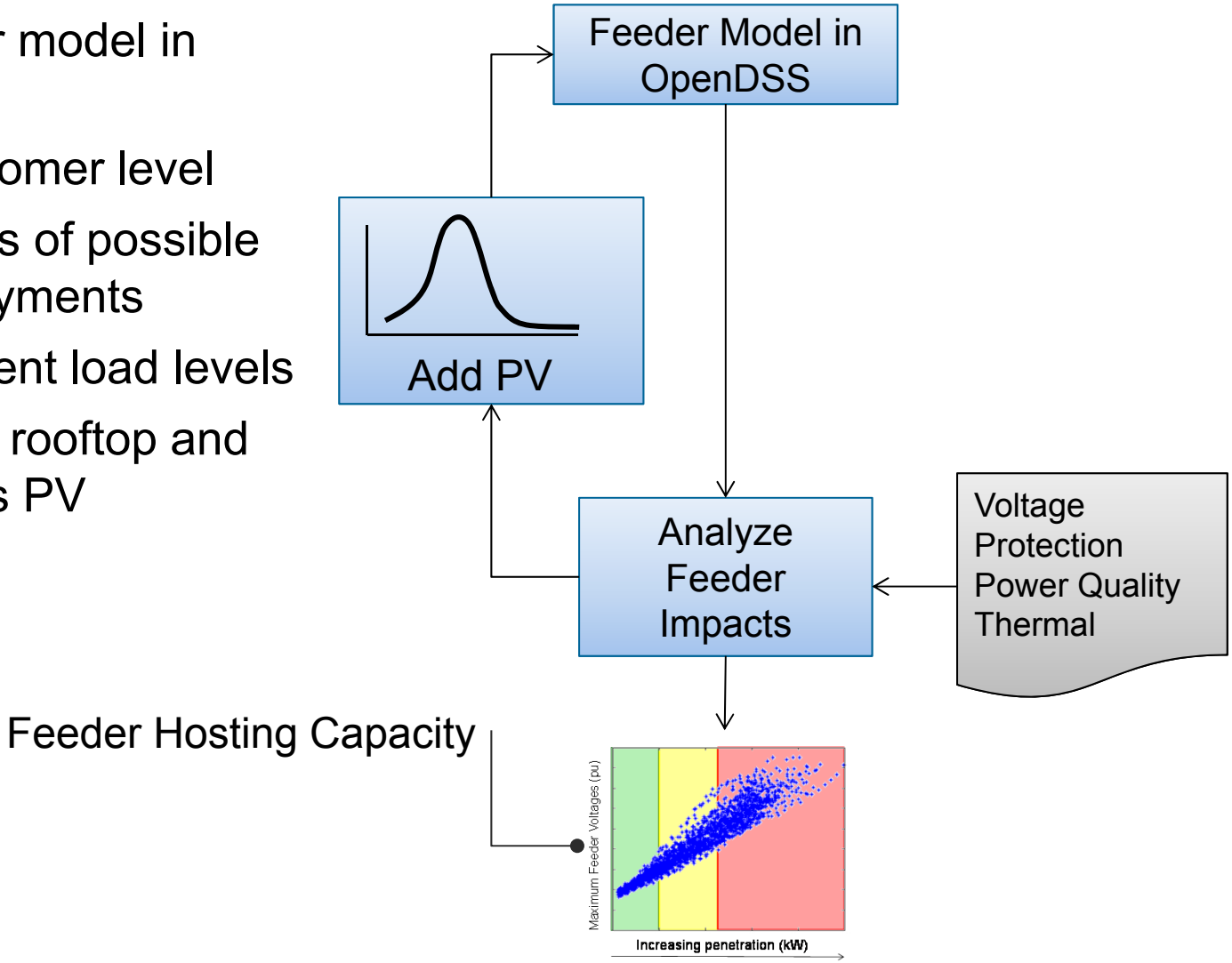
Overall Task Approach

- Detailed feeder model in OpenDSS
- Add PV at customer level
- Evaluate 1000's of possible solar PV deployments
- Consider different load levels
- Consider small rooftop and large MW-class PV



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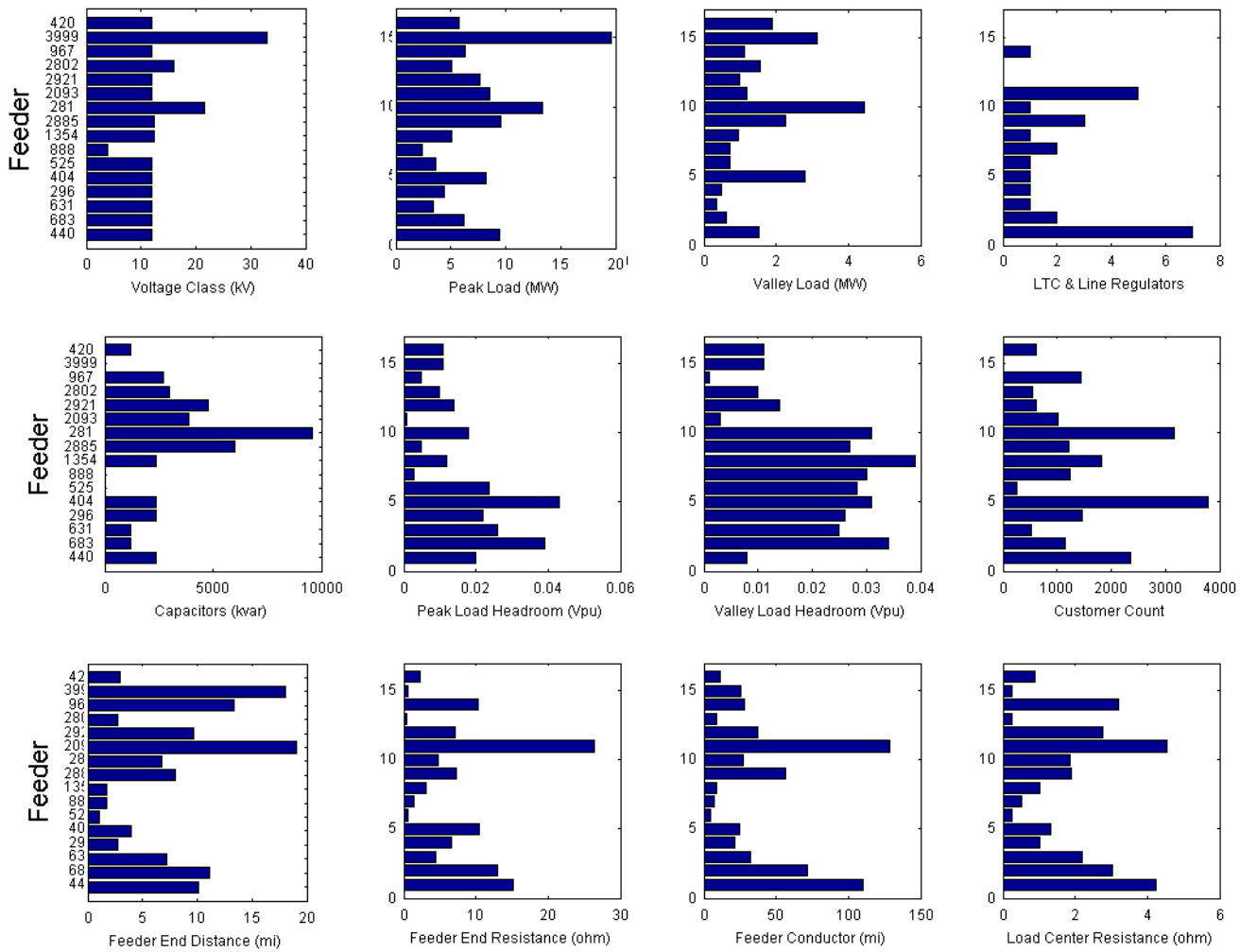
Representative Feeder's Identified from Clustering



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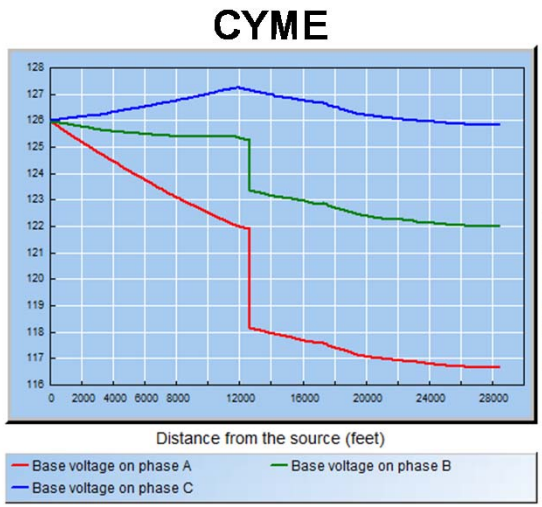
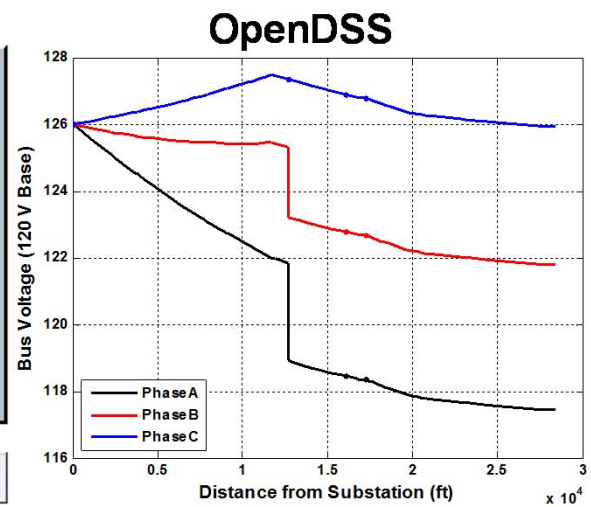
Convert Utility Feeder Models to OpenDSS

- The model is converted from the utilities distribution software platform into the OpenDSS platform
- The feeder model is enhanced using additional data to provide a more detailed representation
- The final validation is made with respect to measurement data





	Power (MVA)	Three-Phase Fault Current	Single-Phase Fault Current	Line-Line Fault Current
OpenDSS	7.35 – j1.44	872	578	746
CYME	7.35 – j1.45	855	586	741

23

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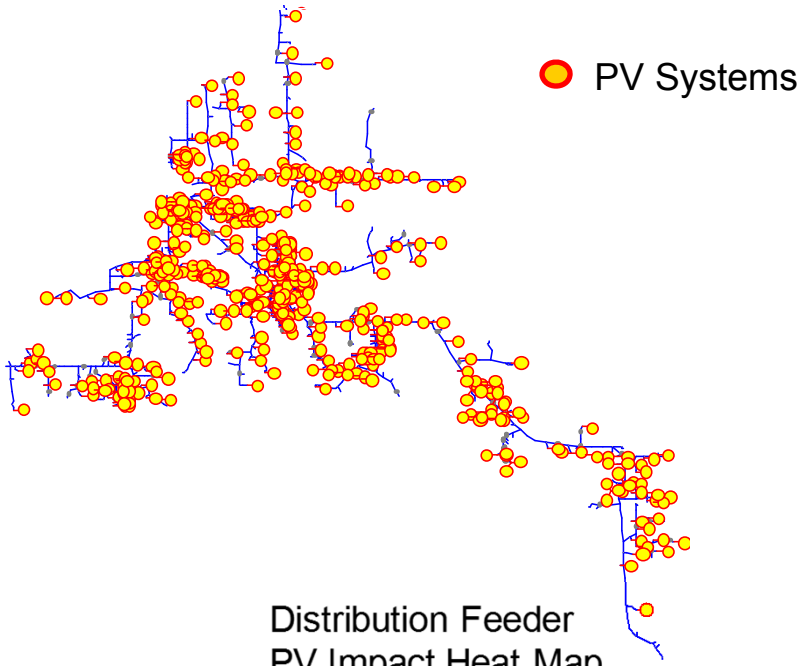
Stochastically Add PV Deployments



Baseline – No PV

PV Penetration 1

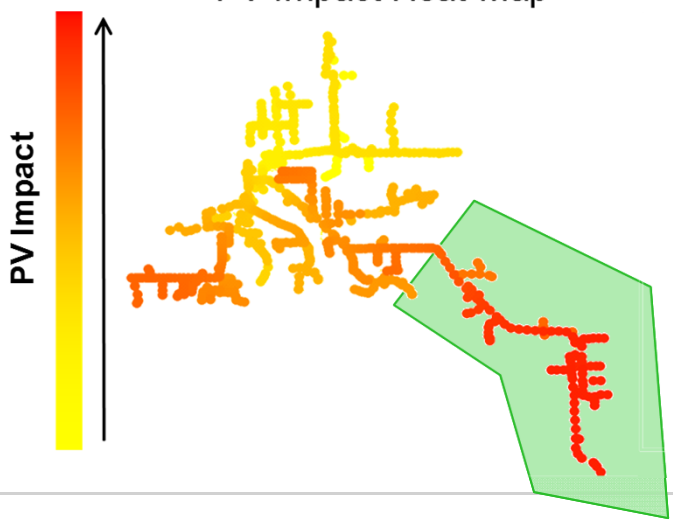
PV Penetration 2

PV Penetration 3

Beyond…

Process is repeated 100s of times to capture many possible scenarios

Distribution Feeder
PV Impact Heat Map



Increase Penetration Levels Until Violations Occur

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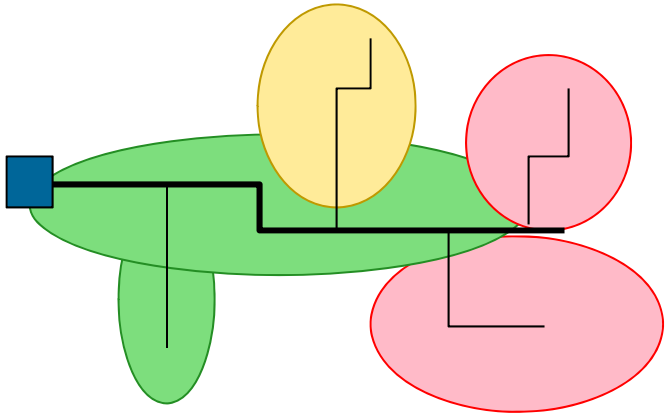
Detailed Feeder Analysis

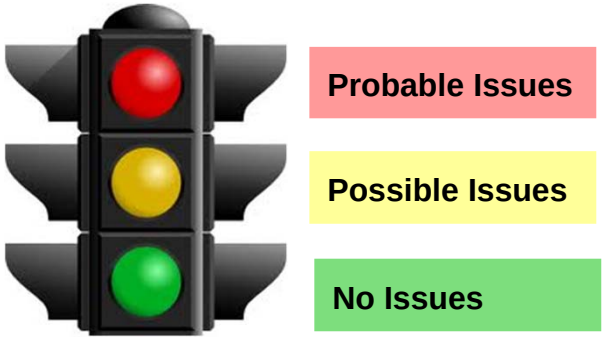
What are we trying to achieve? …Hosting Capacity

Better understanding of PV impacts to distribution feeders

- When do impacts occur
- Where is PV more problematic
- What are the limiting factors
- Why can one feeder accommodate more than another
- …



What is Hosting Capacity?
Amount of PV that can be accommodated on a given feeder without impacting reliability or power quality



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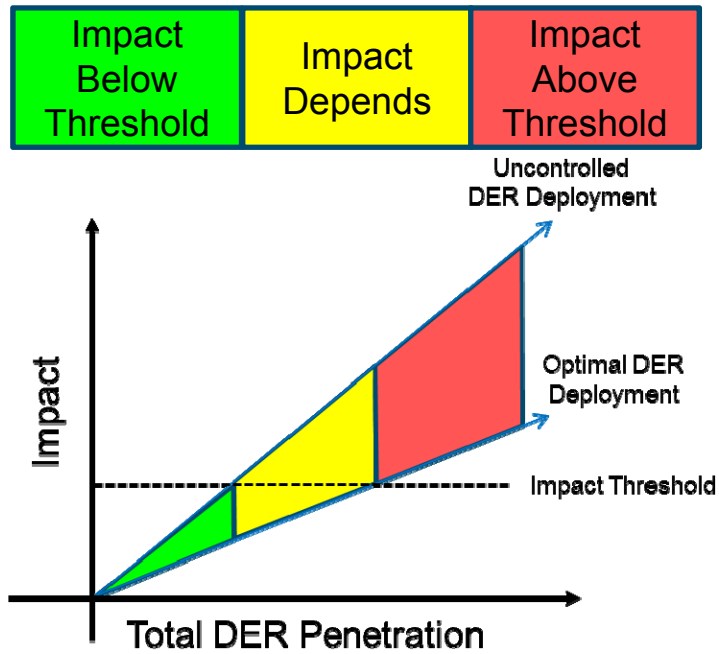
Hosting Capacity
What matters most?

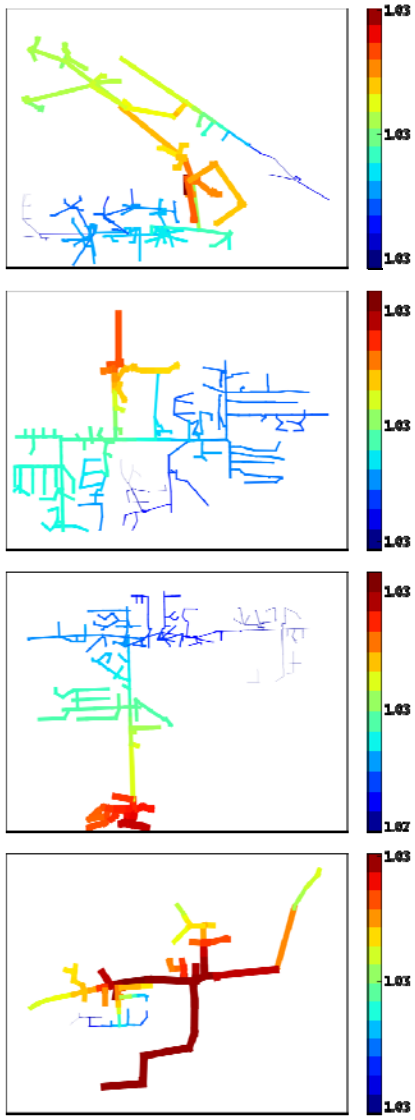
- Feeder issue
- PV size and location
- Feeder design and operation

Voltage

Protection coordination

Thermal capacity





Feeder Isssue

PV Size and Location

Feeder Design and Operation

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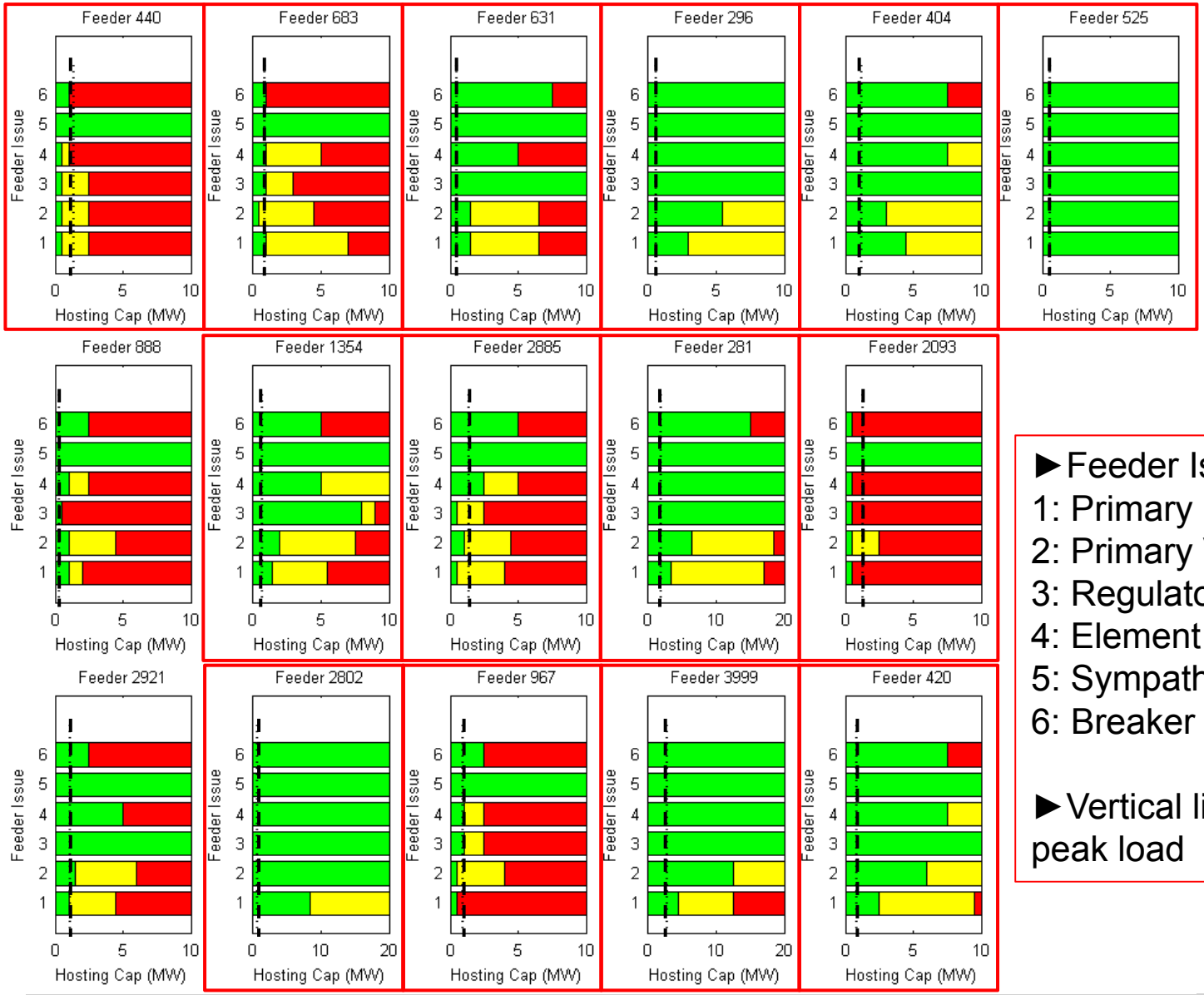
Detailed Hosting Capacity Results



Impact Below Threshold
Impact Depends
Impact Above Threshold

►Feeder Issue
1: Primary Overvoltage
2: Primary Voltage Deviation
3: Regulator Voltage Deviation
4: Element Fault Current
5: Sympathetic Breaker Tripping
6: Breaker Reduction of Reach

►Vertical lines indicate 15% of peak load

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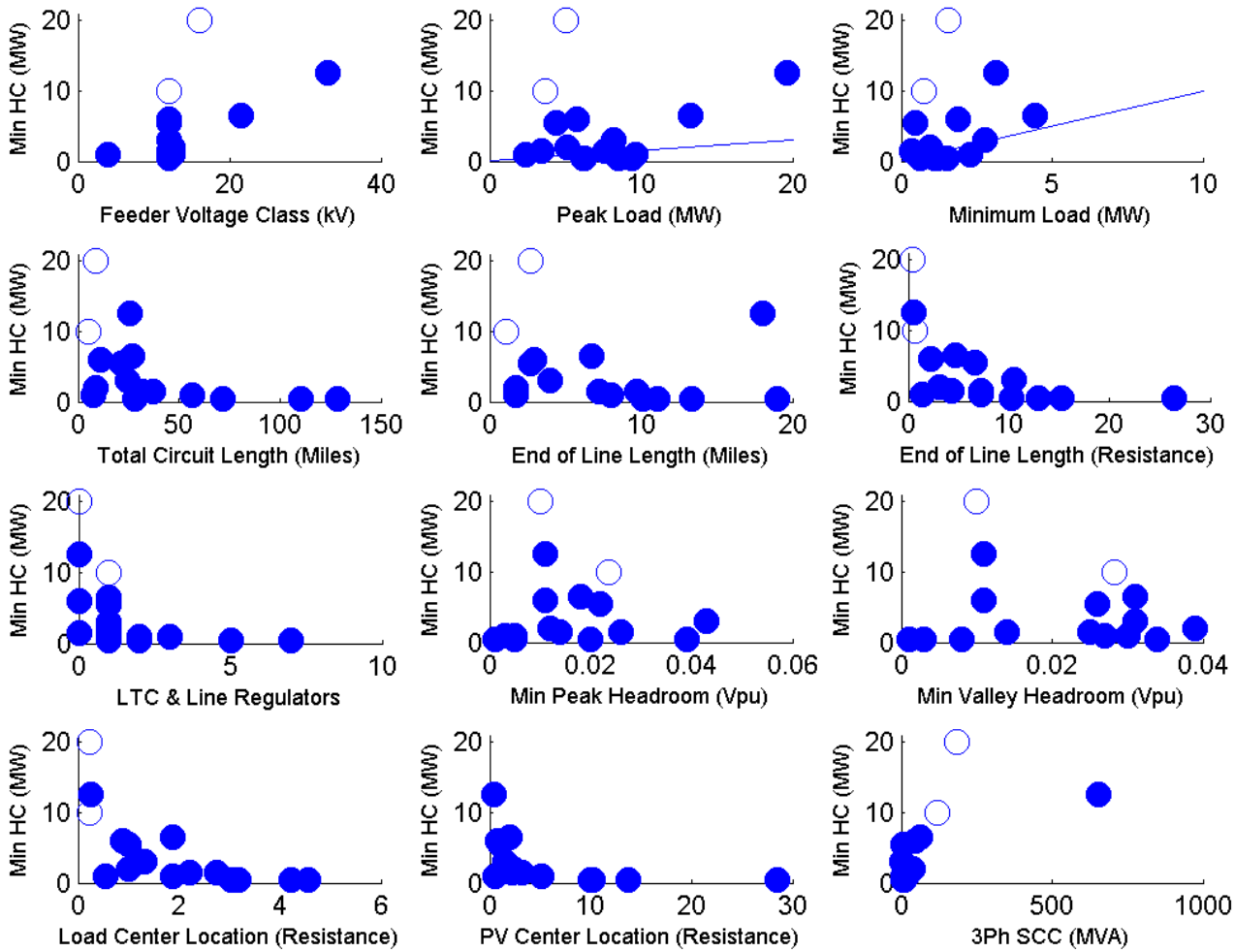
Correlations – What Characteristics Matter



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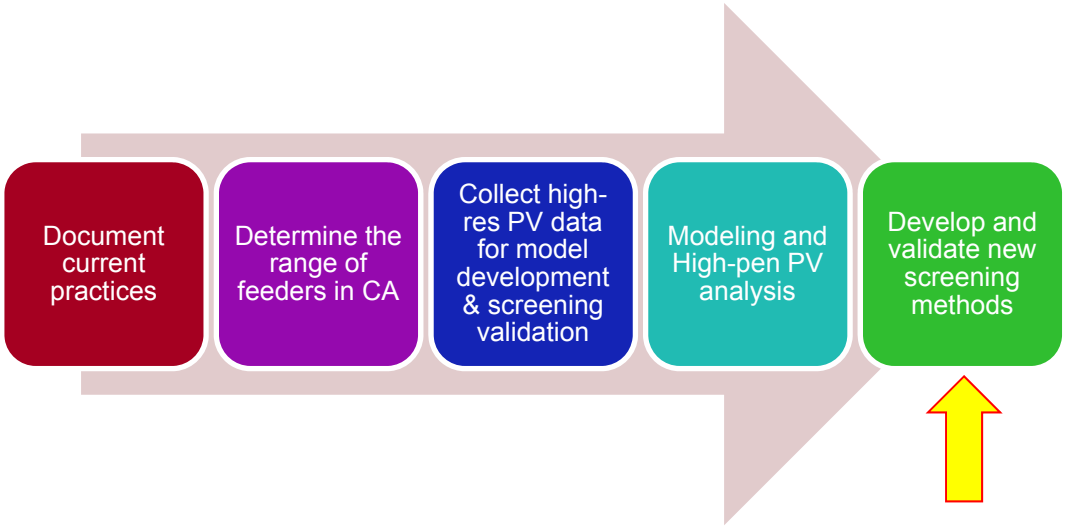
Project Task: Develop and Validate Screening Methodology



Alternatives to the 15% Rule: Modified Screens and Validation. EPRI, Palo Alto, CA: 2015. 3002005791.

- Task Purpose
  - Develop and validate a practical screening criterion for evaluating new interconnection requests in aggregate with existing PV
- Approach
  - Analyze results from PV study
  - Develop improved screening methodology
  - Validate method using control group of feeders

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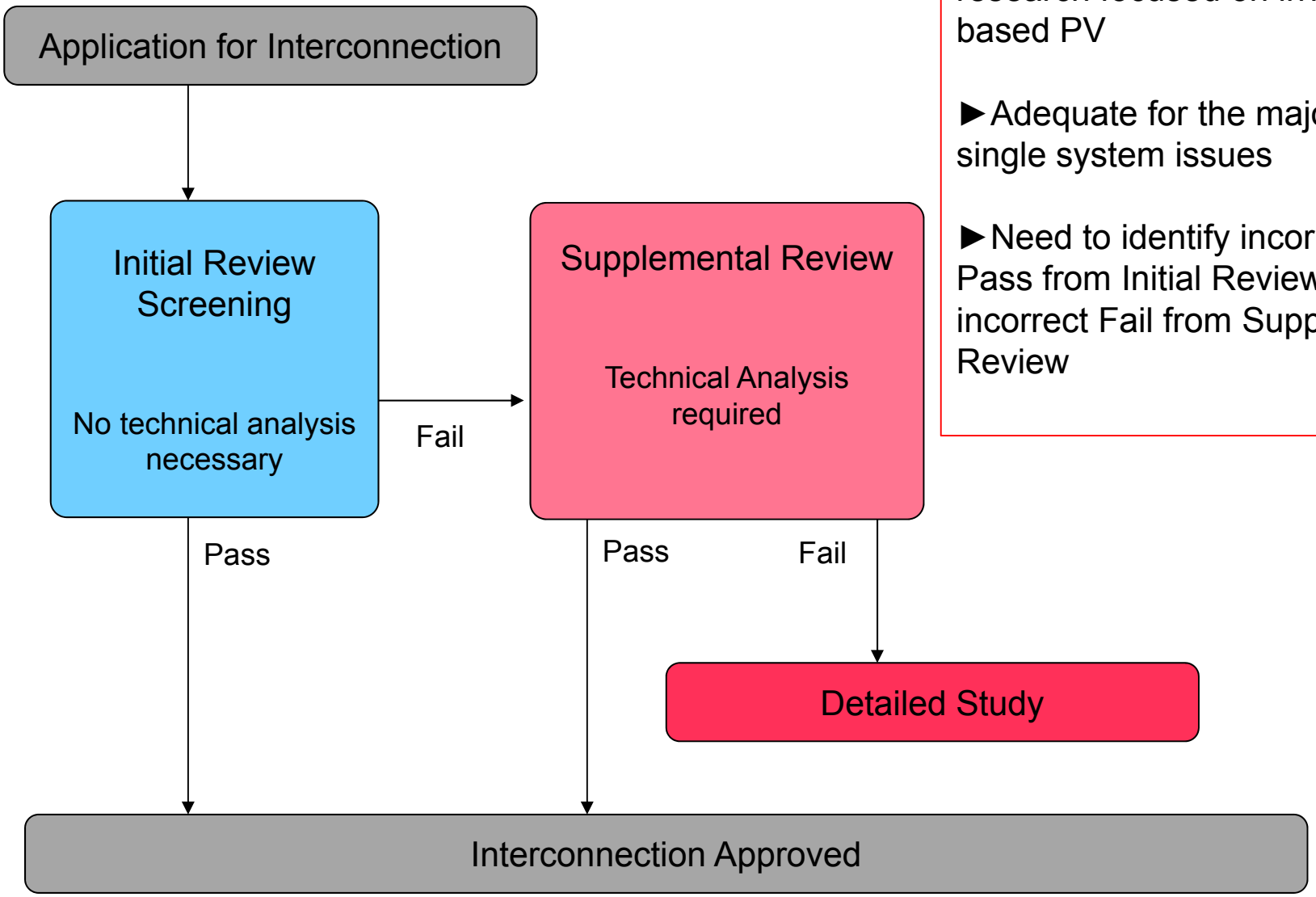
Overview of CA Rule 21



►Inclusive of all types of distributed generation while this research focused on inverter-based PV

►Adequate for the majority of single system issues

►Need to identify incorrect Pass from Initial Review and incorrect Fail from Supplemental Review

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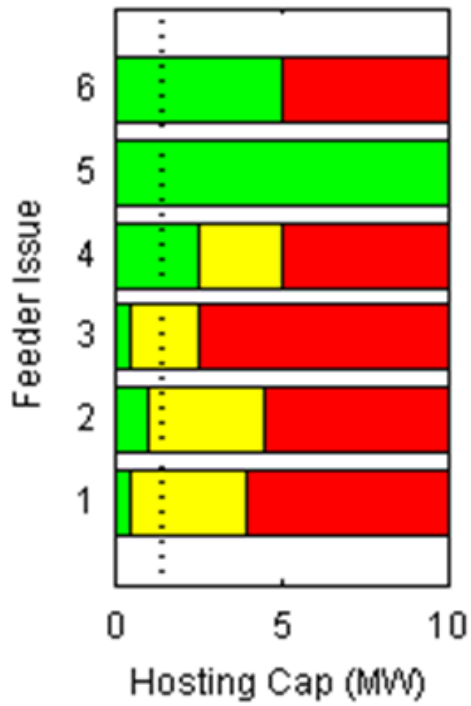
Identify Gaps and Improvement for CA Rule 21

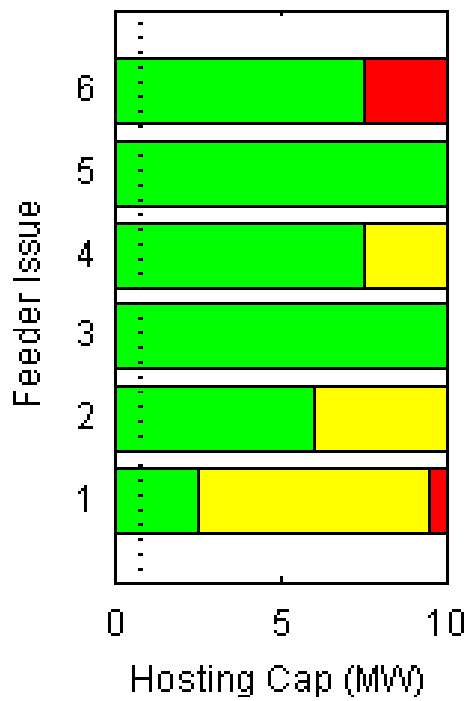
Incorrect Pass of Initial Review

- Impact may occur well below a specific percent of load



Incorrect Failure of Supplemental Review

- Impact may not occur until much higher than a specific percent of load



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Impact Depends
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6: Breaker Reduction of Reach

►Vertical lines indicate 15% of peak load

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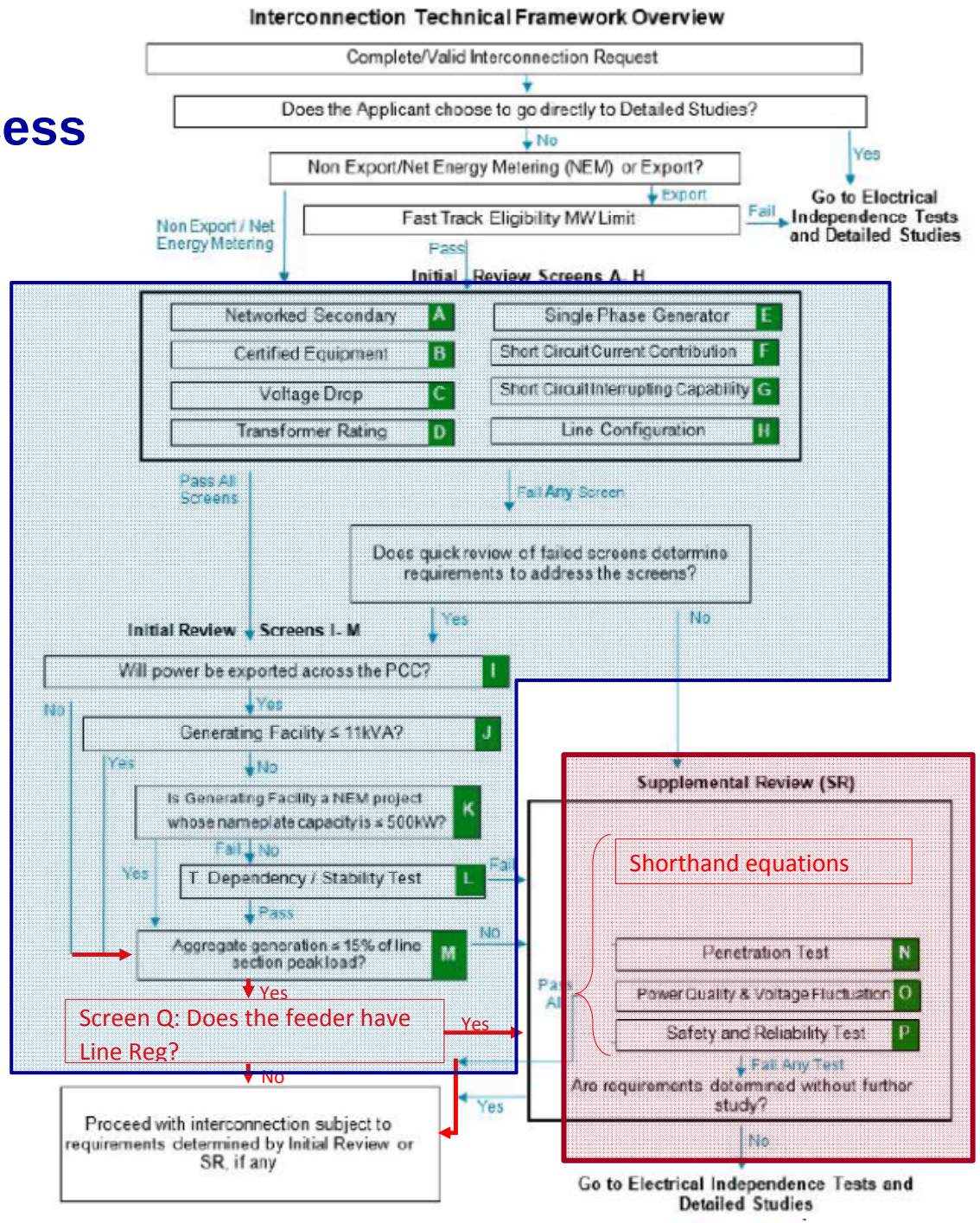
CA Rule 21
Modified Screening Process

Initial Review Screens

- Add screen that considers if the feeder has line regulators
- Always consider aggregate generation

Supplemental Review

- Add simple equations to estimate hosting capacity



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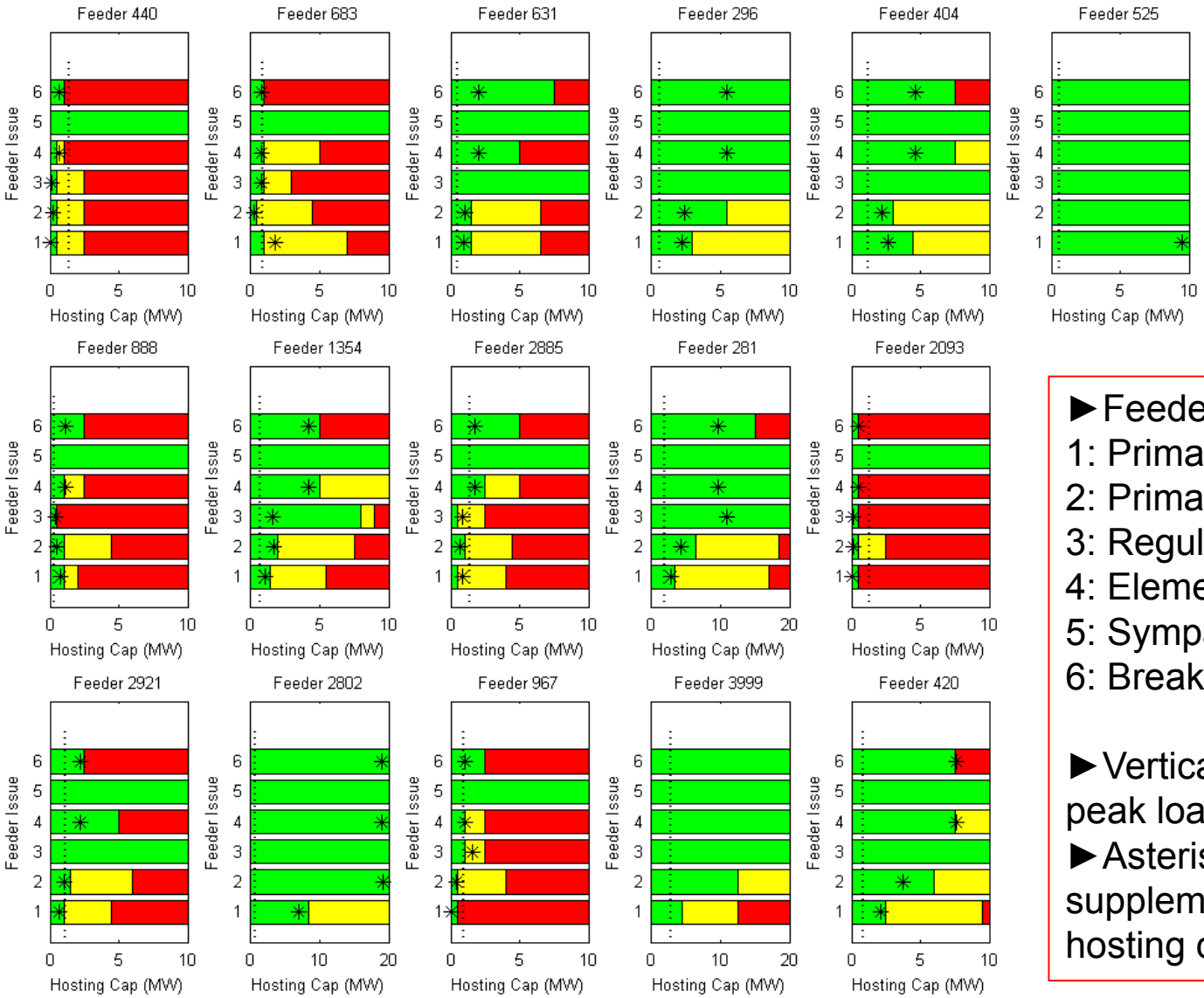
Detailed Hosting Capacity and Supplemental Review Estimates



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►Vertical lines indicate 15% of peak load
►Asterisks indicate supplemental review estimated hosting capacity

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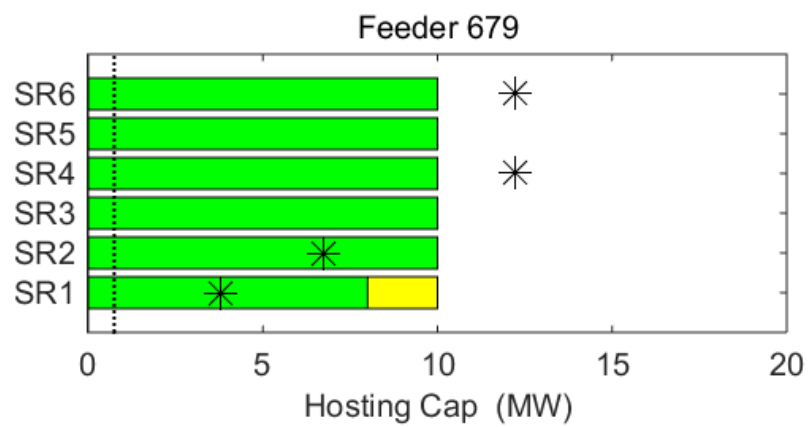
Validation

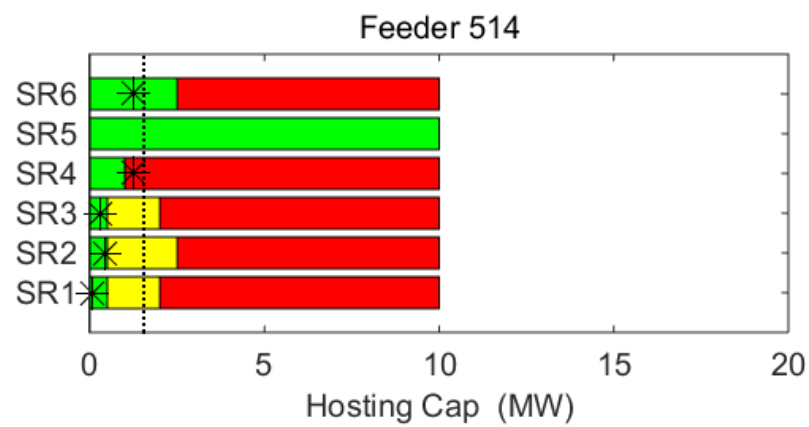
Initial Review

- Feeder 679 does not contain a line regulator
  - As expected, hosting capacities are above the 15% load limit
- Feeder 514 does contains a line regulator
  - As expected, hosting capacities are below the 15% load limit
  - Feeder subjected to the supplemental review process immediately as opposed to allowing PV deployment up to 15% of peak load and then implementing the supplemental review
- At some point, the aggregate generation on the feeder will cause adverse impact

Supplemental Review

- Asterisks indicate the feeders' estimated ability to accommodate PV
- Independent of load level and better matches the detailed analysis





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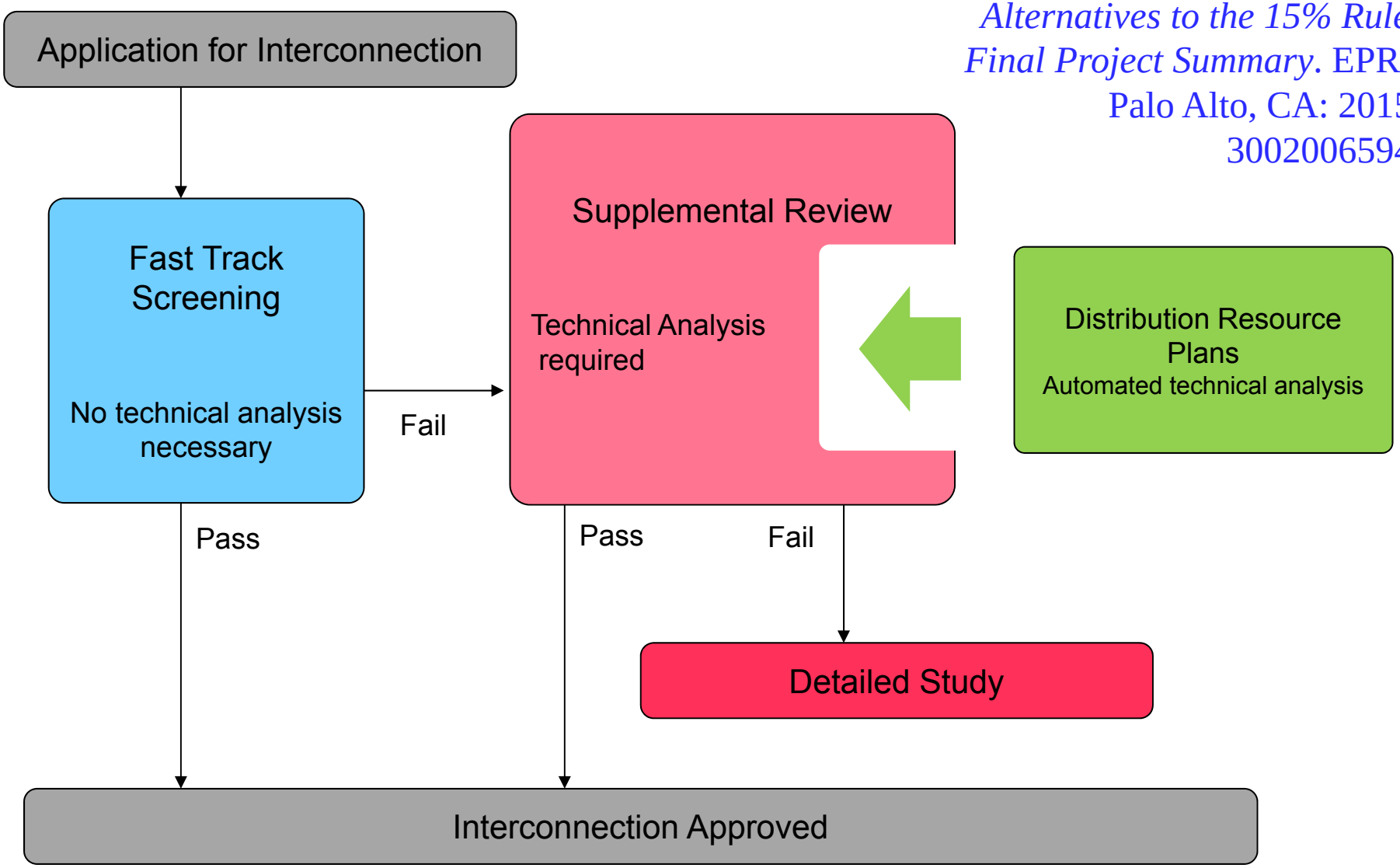
Long-Term Solution

Screening that's in Coordination with Distribution Resource Plans (DRP)

Alternatives to the 15% Rule: Final Project Summary. EPRI, Palo Alto, CA: 2015. 3002006594.



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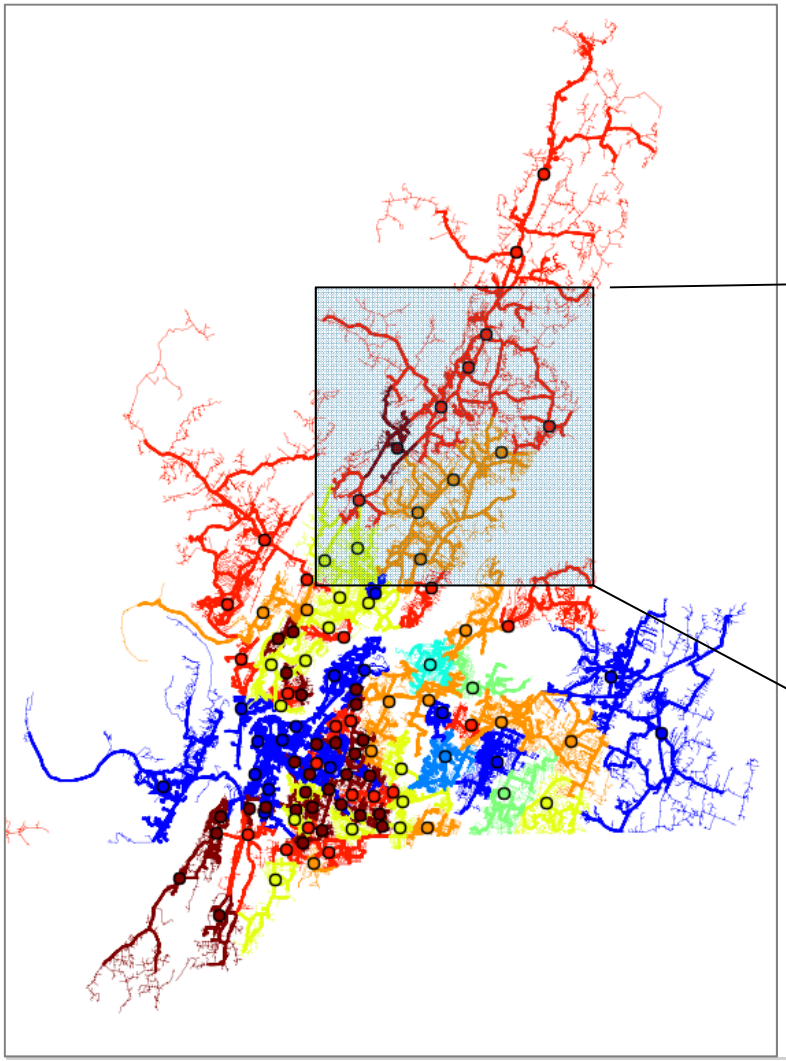
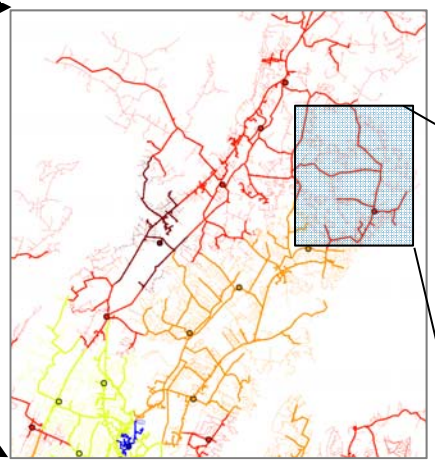
EPRI's DRP (Streamlined Hosting Methodology) Sample Results

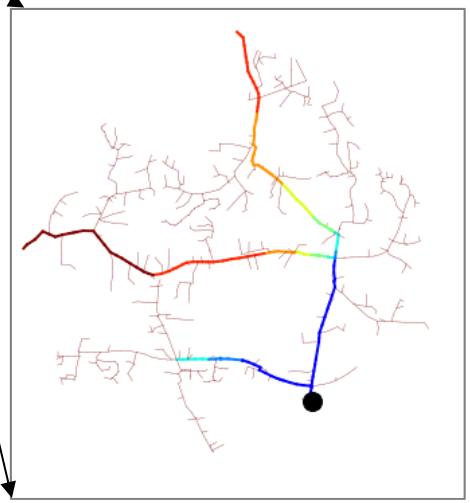
System Hosting Capacity
(~ 300 distribution feeders)



Substation-level Hosting Capacity



Feeder-level Hosting Capacity



***Hosting Capacity**

lower

higher

○ **Substation Marker**

**Sample results applying EPRI's Streamlined Hosting Method for DOE/TVA study, initial results, not finalized*

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Conclusions

- Current utility planning methods
  - Not consistent nationwide, but planning procedure like CA Rule 21 helps provide uniformity
- Clustering
  - Great way to identify different feeders
- Detailed modeling and analysis
  - Can accurately determine impacts from distributed generation but at the cost of time and resources
- Modified Screening
  - Add an Initial Review screen that addresses if the feeder has line regulators
  - Modify the Initial Review to always account for aggregate generation
  - Add Supplemental Review equations to address the impacts of aggregate generation for issues not solely dependent on load
- Long-term Solution
  - Coordinate screening with establishment of Distribution Resource Plans that account for the locational impact and value of all forms of DER

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Public Link to Reports Online

http://calsolarresearch.ca.gov/funded-projects/88-screening-distribution-feeders-alternatives-to-the-15-rule

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Alternatives to the 15% Rule: Modeling and Hosting Capacity Analysis of 16 Feeders. EPRI, Palo Alto, CA: 2015. 3002005812.

Alternatives to the 15% Rule: Modified Screens and Validation. EPRI, Palo Alto, CA: 2015. 3002005791.

Alternatives to the 15% Rule: Final Project Summary. EPRI, Palo Alto, CA: 2015. 3002006594.

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Backup Slides

40

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Utility Cluster Means

Utility 1:

Feeder Count	Primary Voltage	Total 3-Phase miles	Total 1 & 2 Phase miles	Ind Cust	Agr Cust	Total Cust	Regulators	Capacitors	Boosters	Reclosers + Sectionalizers	Summer KVA Capability	Summer/Winter	90% Radius
136	12.29	48.41	57.99	30	26	2218	4.54	4.5	0.35	4.94	9650.82	1.14	38.78
735	12	20.31	11.02	62	5	2929	0.3	4.96	0.07	1.97	11309.24	1.29	15.06
114	12.86	132.15	15.78	19	286	1232	6.89	6.82	2.18	5.5	10902.51	1.96	85.54
290	12.02	64.6	6.38	16	108	750	3.27	4.94	0.94	2.88	9540.62	1.81	25.37
94	12	49.6	40.86	35	26	1794	3.09	5.01	3.16	4.32	9481.72	1.2	36.11
214	20.64	41.3	31.09	74	25	3628	1.11	5.72	0.24	4.68	20083.13	1.58	56.56
237	21.01	18.55	10.52	63	6	1713	0.31	3.21	0.08	1.31	19202.85	1.47	29.1
410	4	3.79	2.16	7	0	883	0.11	1.48	0.03	0.19	2497.93	0.94	4.35
749	12.01	10.49	3.57	27	5	704	0.26	2.09	0.07	0.54	9335.52	1.19	13.53
59	13.02	88.78	116.11	31	53	2653	8.61	5.97	1.97	8.22	10683.2	1.29	74.77

Utility 2

Cluster	Feeder count	Nominal, voltage, kV	Total 3-ph ckt miles, mi	Total 2-ph and 1-ph ckt miles, mi	Number of switched/fixed capacitor banks, #	Number of feeder tie points, #	Connected service transformer capacity, kVA	Feeder peak load, kVA (calculated)	Total customer count	Industrial customer count	Other customer count	Peak season	90% Radius
1	70	12.57	31.86	38.92	5.89	4.97	19094	6707	1536	1.74	32.64	2.97	57
2	63	33	19.14	0.14	0.06	2.14	3969	12177	8	0.73	1.71	2.84	43.2
3	174	14.05	9.06	2.13	4.33	7.38	21134	7607	1489	29.99	12.83	2.89	44.1
4*	130	12.83	25.17	7.12	4.32	6.28	12711	4977	829	2.27	74.06	2.79	45.7
5	950	4	2.9	2.21	1.8	2.61	2199	1609	665	0.51	2.43	2.56	9.8
6	1184	12.66	6.87	3.3	2.4	4.75	10426	5502	685	194	6.09	2.87	21.5
7	1404	12.89	11.1	9.49	4.37	7.67	16730	8960	1875	2.01	11.12	2.9	26.4
8	73	12.49	37.57	3.87	5.41	8.12	15351	5752	796	2.1	265.7	2.82	69

Utility 3

Cluster	Total 3-ph ckt miles	Total 2-ph and 1-ph ckt miles	Number of line voltage regulators, #	Cap Banks	Number of feeder tie points, #	Connected service transformer capacity, kVA	Feeder peak load, kW	Residential, %	Commercial, %	Industrial, %	Hour	Count
1	29.17	34.56	1.58	1.90	1.94	20620.39	5532.90	82.42	17.50	0.07	12.50	31
2	16.04	14.17	0.06	2.03	2.70	21348.99	8523.84	90.62	9.34	0.04	15.01	263
3	2.17	0.02	0.00	1.18	1.05	5779.09	6061.82	0.00	49.70	50.30	14.47	22
4	7.86	4.92	0.02	1.26	1.97	12831.42	6118.02	86.38	13.44	0.17	13.77	283
5	5.81	0.27	0.03	1.31	1.88	13283.80	6111.84	4.62	84.82	3.31	11.78	152

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Data needed for Supplemental Review (SR) Equations

Feeder Related

- **Feeder Resistance:** Resistance to last three-phase node
- **Feeder Impedance:** Impedance to last three-phase node
- **Feeder Voltage Class:** Primary voltage class of the feeder
- **Regulators:**
  - Resistance to regulator
  - Bandwidth
  - Line drop compensation settings

DER Related

- **DER Fault Current:** Fault current contribution in PU of rated

Analysis Thresholds

- Voltage Headroom
- Allowable primary Voltage Deviation
- Allowable percent increase in fault current
- Allowable percent decrease in breaker sensitivity
- Allowable current rise on breaker ground relay

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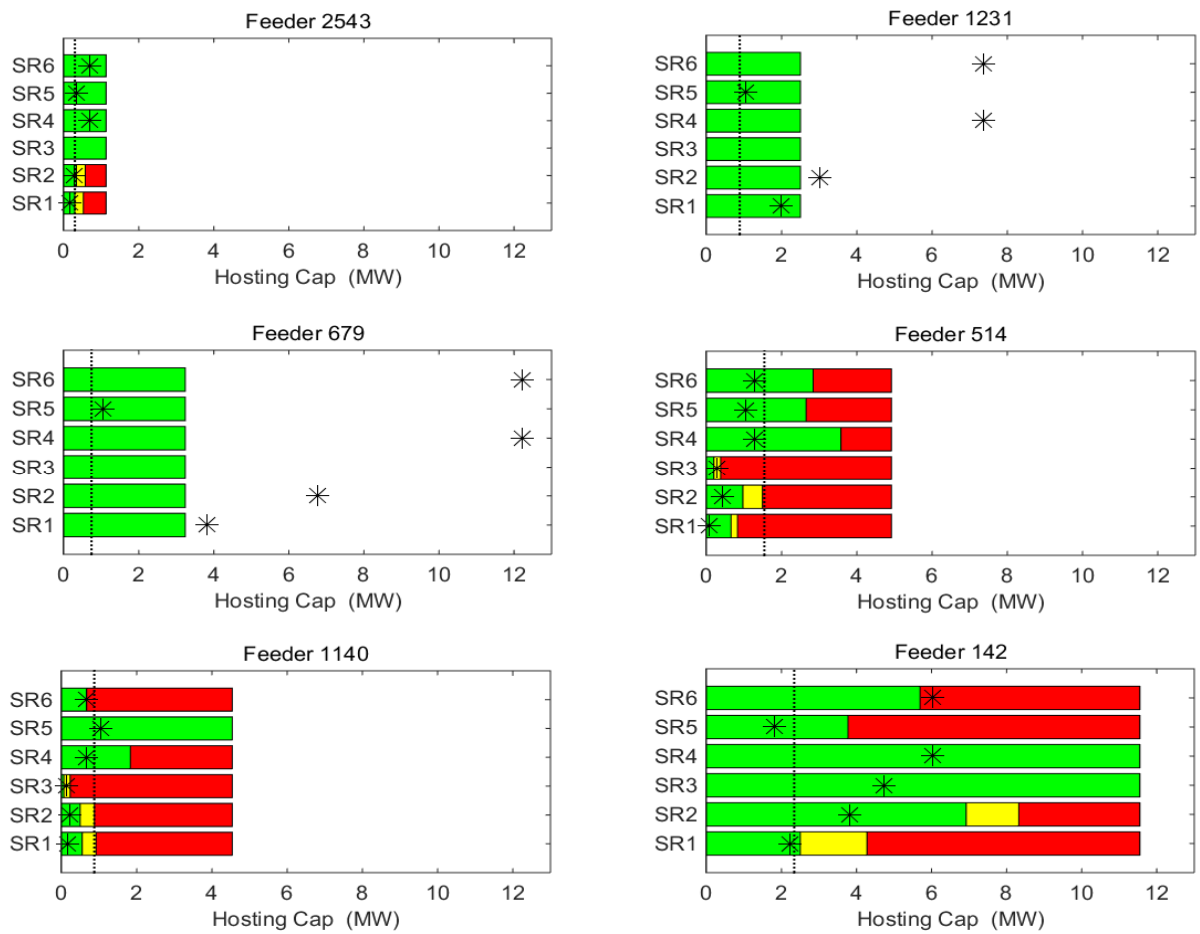
Validation of Proposed Modifications (proposed SR changes)

- Asterisks demark SR calculated hosting capacities



- SR1 – Primary overvoltage
- SR2 – Primary voltage deviation
- SR3 – Regulator voltage deviation
- SR4 – Element fault current
- SR5 – Sympathetic breaker tripping
- SR6 – Breaker reduction of reach

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