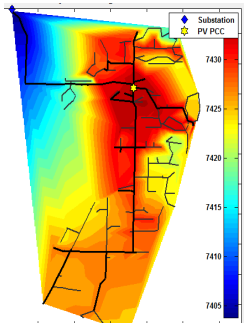
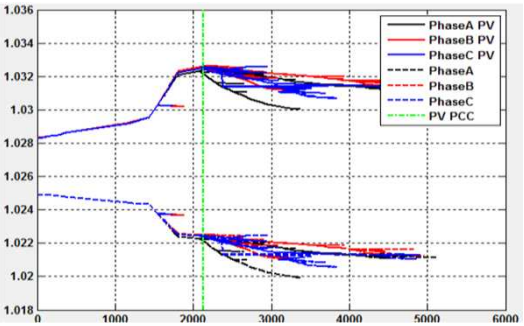
SAND2015-10018PE

Best Practices for Distribution Systems with High PV Penetration





UVIG Contemporary Grid Issues for Photovoltaics

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Outline

- Introduction
- What is going wrong with the Small Generator Interconnection Procedure (SGIP) process?
- What is the accuracy of new screening methods?
- Can we use feeder clustering to map PV impacts?
- Conclusions

Analysis of Utility SGIP PV Studies

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Three evaluation procedures:

- 10 kW Inverter Process
- Fast Track process
- Study Process

SNL surveyed 100 PV SGIP studies to:

- Classify interconnection types and facility costs
- Analyze the types of adverse system impacts

100 SGIP Cases Dataset

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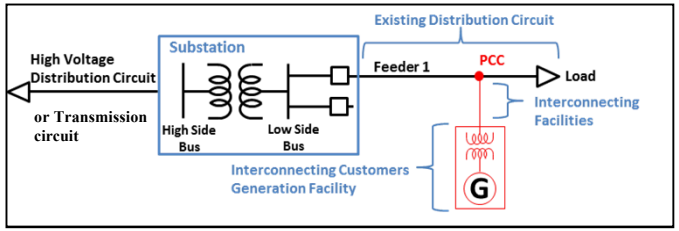
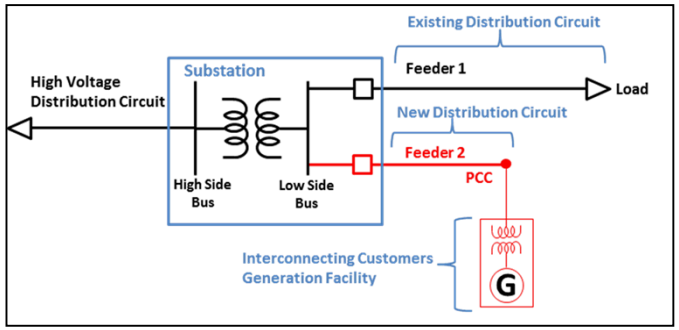
- PV facility sizes ranged from 1 MW to 20 MW.
- Facilities entered study process by failing fast track screens and other requirements.
- Studies performed by 9 utilities:
  - PNM Resources
  - Arizona Public Service
  - Pacific Power
  - Rocky Mountain Power
  - PacifiCorp Energy
  - Jersey Central Power and Light with PJM
  - Atlantic City Electric with PJM
  - First Energy with PJM
  - Public Service Electric and Gas Company with PJM
- Study data from West Trans Oasis (oatioasis.com) webpages & PJM webpages.

Three Interconnection Topologies

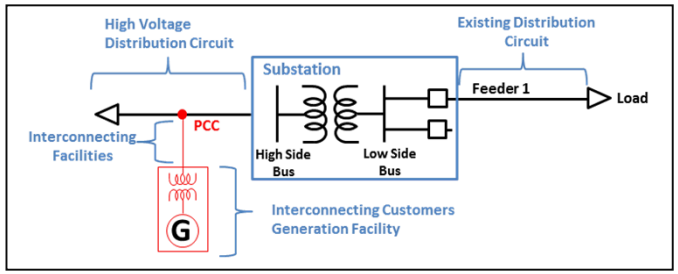
Tap Existing Low Voltage Distribution Circuit.
(Ranged from 12.47 to 34.5 kV.)



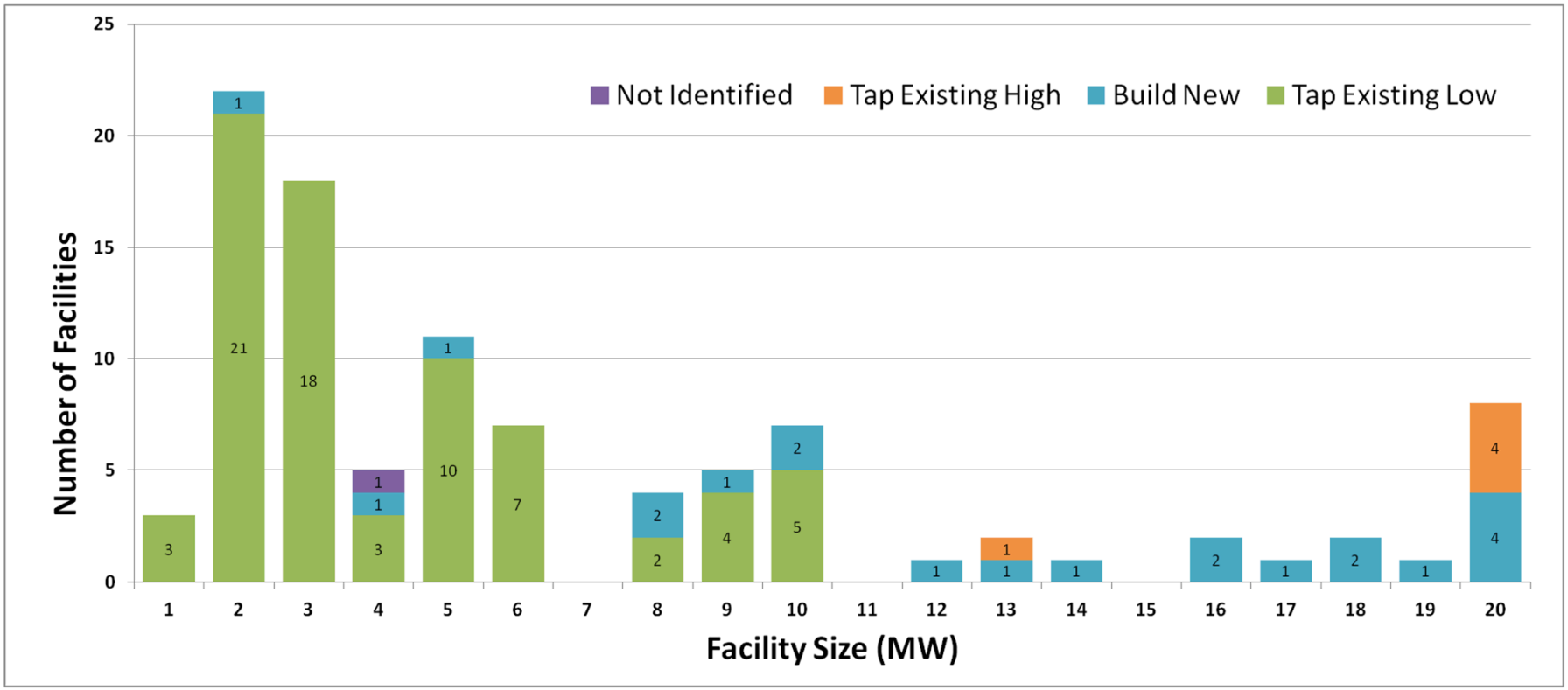
Build New Distribution Circuit from Substation.
(Single or Double feeder service)



Tap Existing High Voltage Distribution Circuit.
(69 kV or less)



General Statistics – Facility Sizes and Interconnection Topology

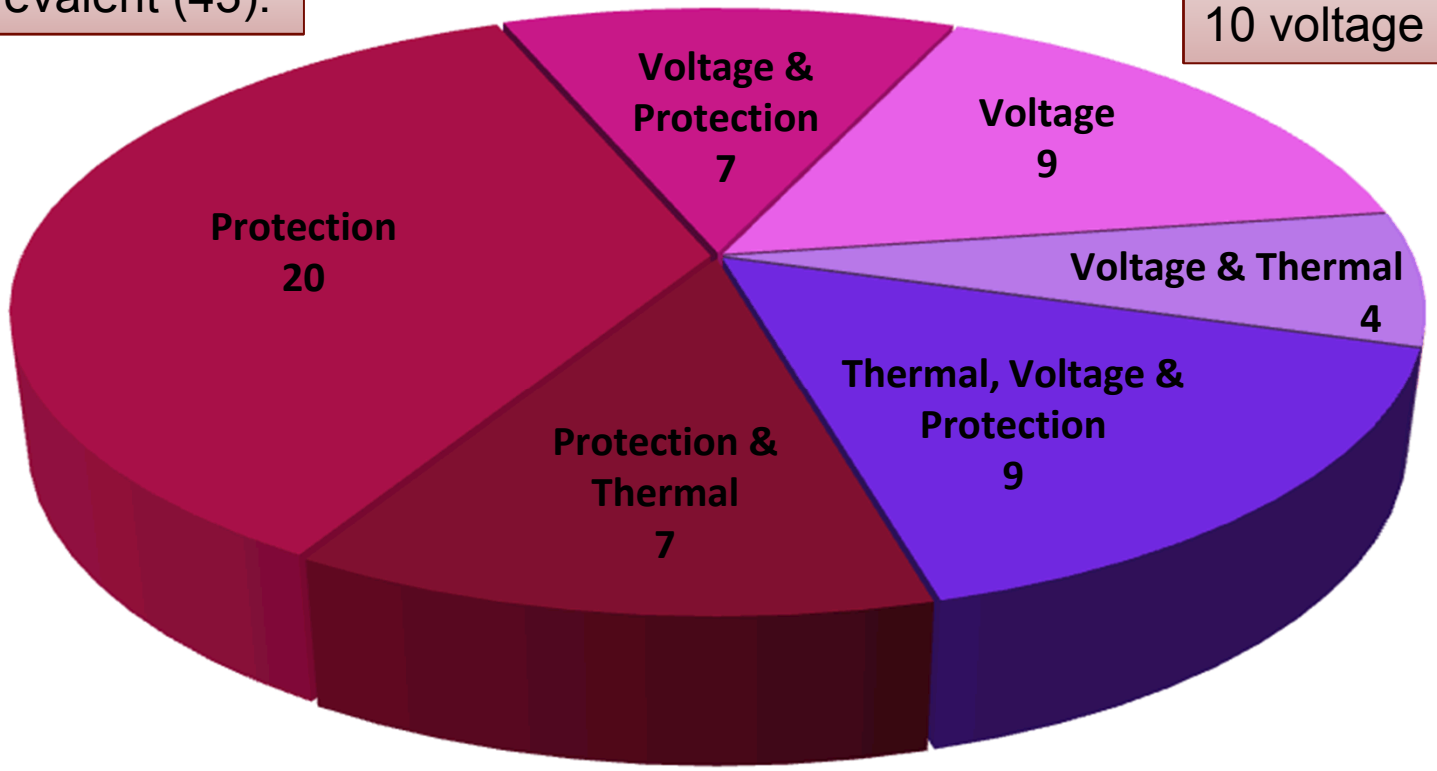


All “Tap Existing Low” were 10 MW or less, 80% of “Tap Existing High” were 20 MW.

Impacts Identified – Impact Type

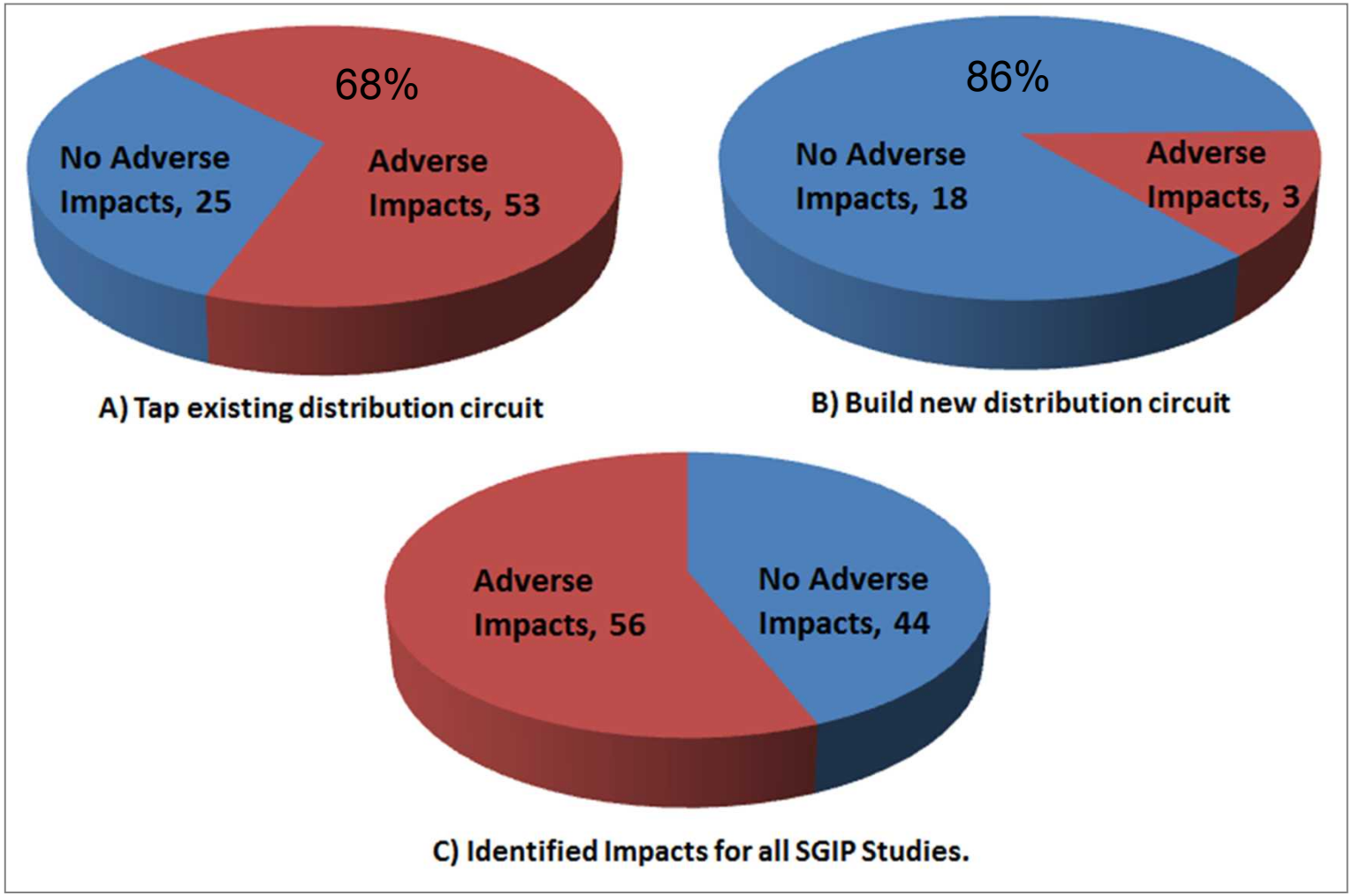
Protection impacts most prevalent (43).

29 voltage impacts – 19 overvoltage and 10 voltage deviation.



All thermal impacts occurred in conjunction with another impact type.

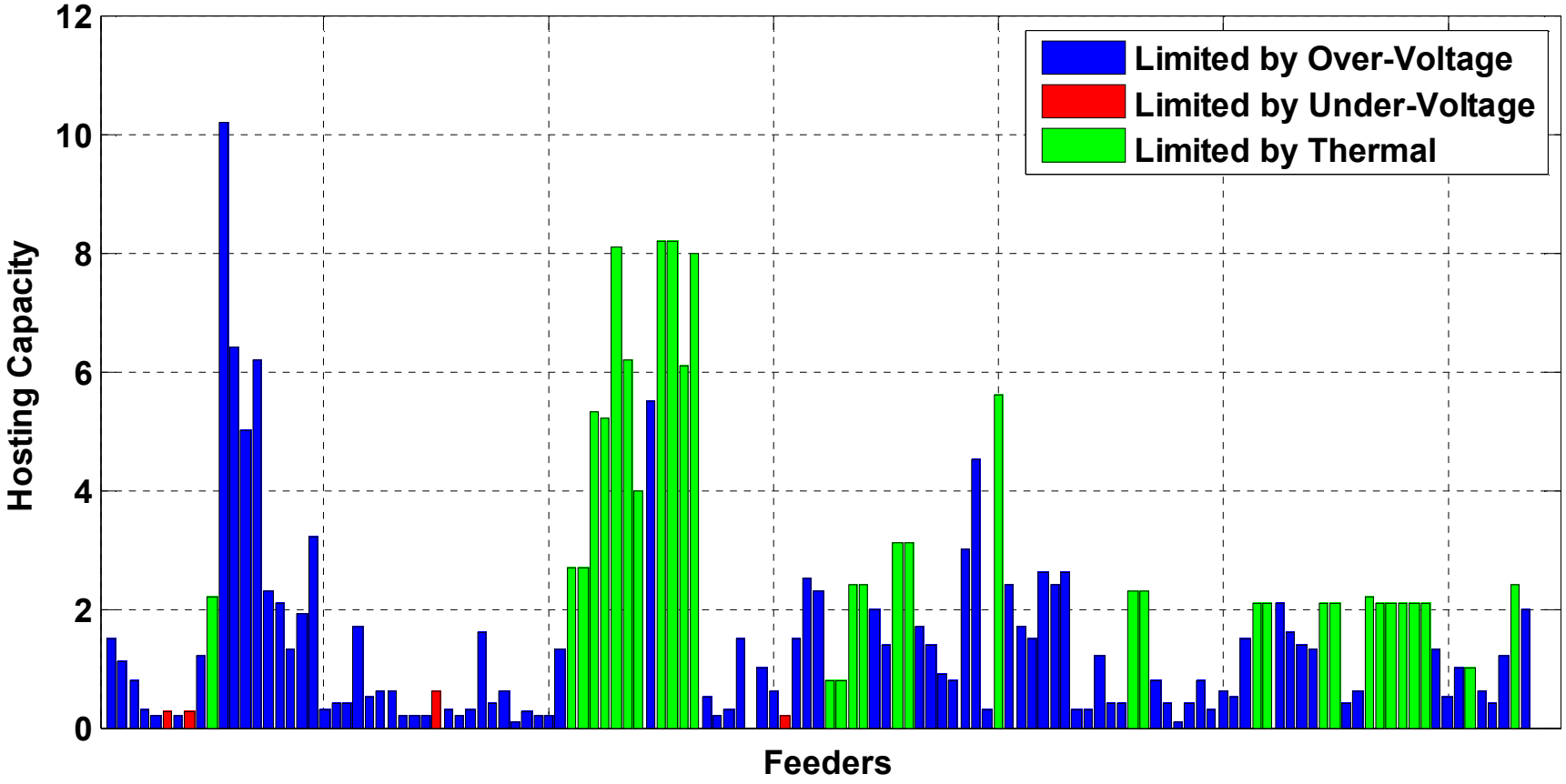
Impacts Identified – Interconnection Topology



SGIP analysis summary

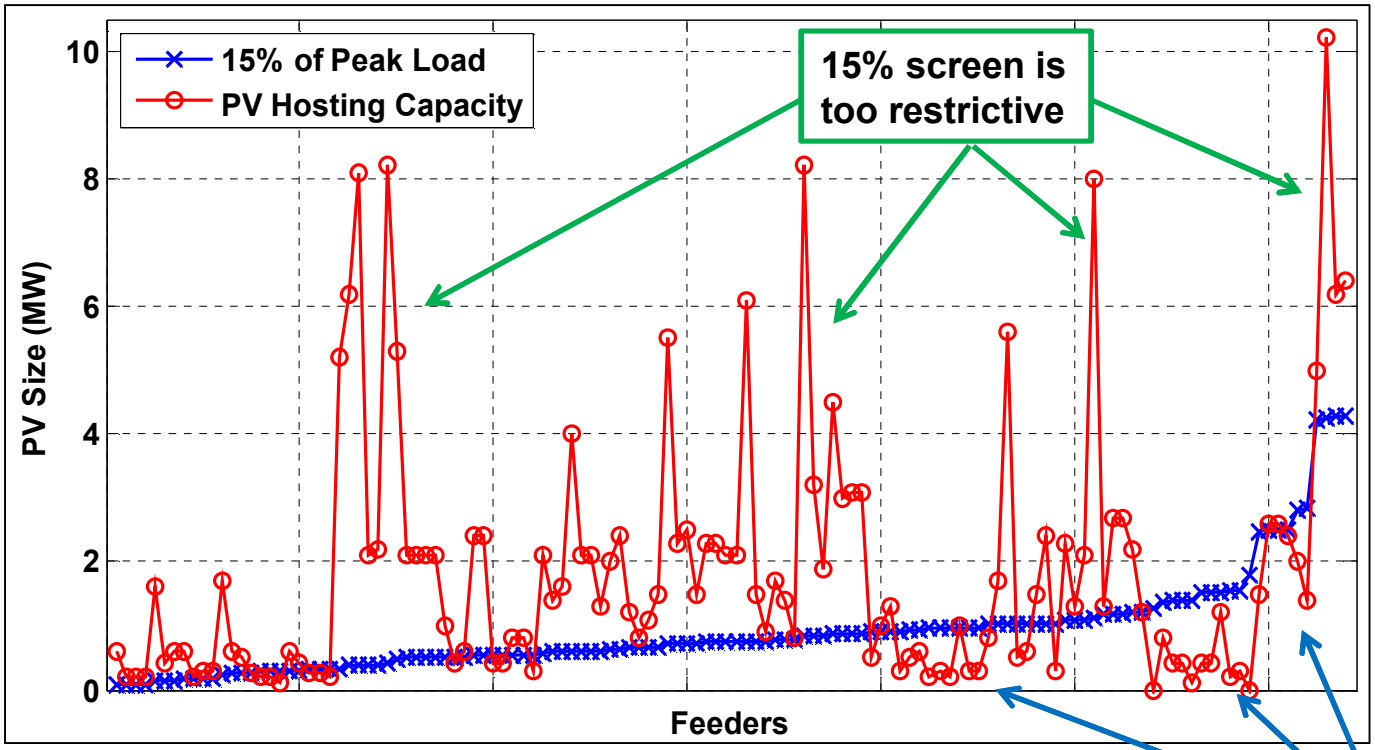
- Overall: NO Adverse impacts on 44 out 100 studies
- Interconnection topologies were strongly correlated to the presence/absence of adverse impacts.
- ***Is there a better way to screen interconnection requests?***

Hosting Capacity for 128 feeders



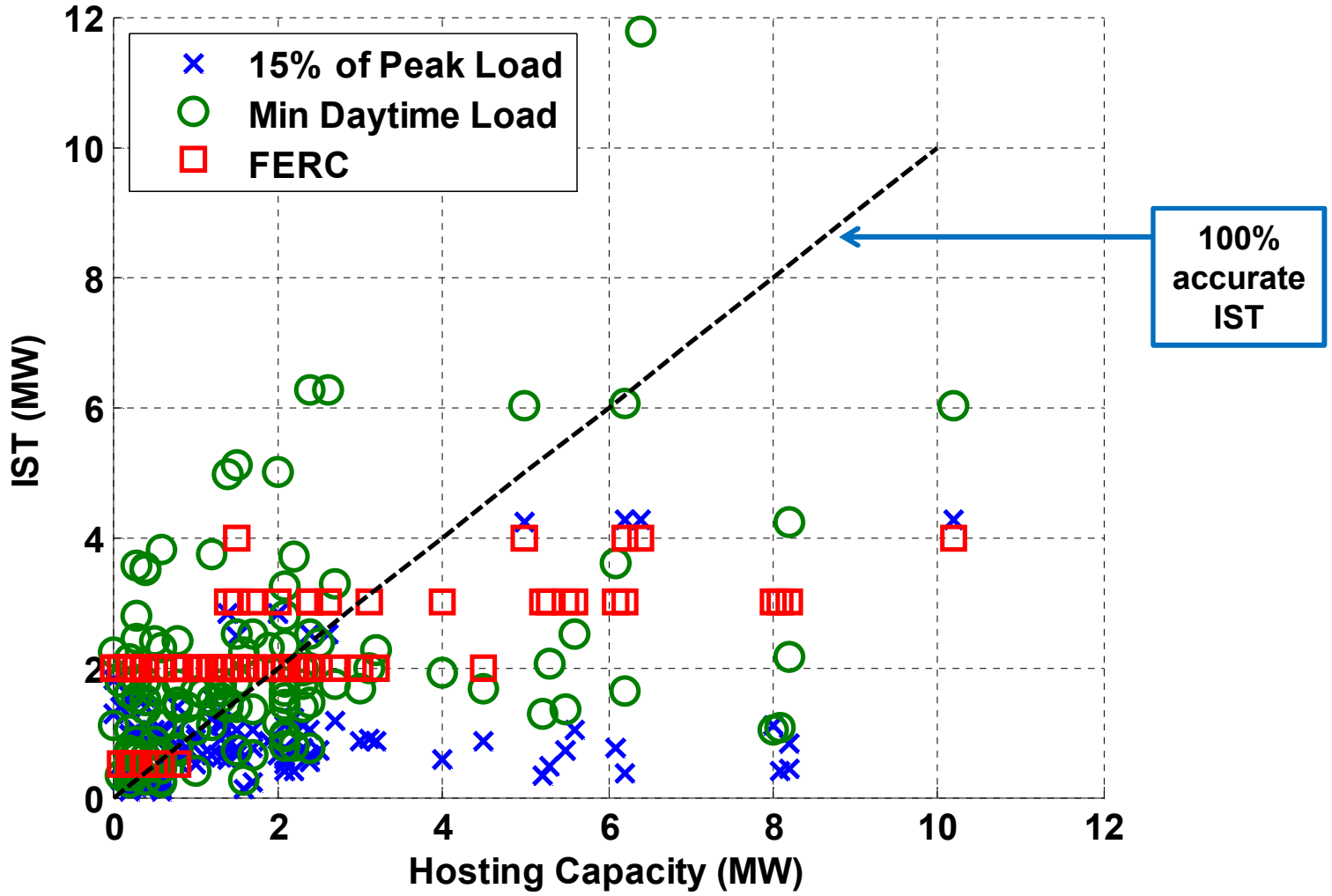
- Analyses captures a wide range of feeder types, voltages, topologies and controls.
- For the 128 feeders, 70% of the feeders are limited by over-voltages on the feeder, 3% of the feeders are limited by under-voltages, and 26% are limited by the thermal ratings.

Accuracy of 15% of peak load screen for 128 feeders

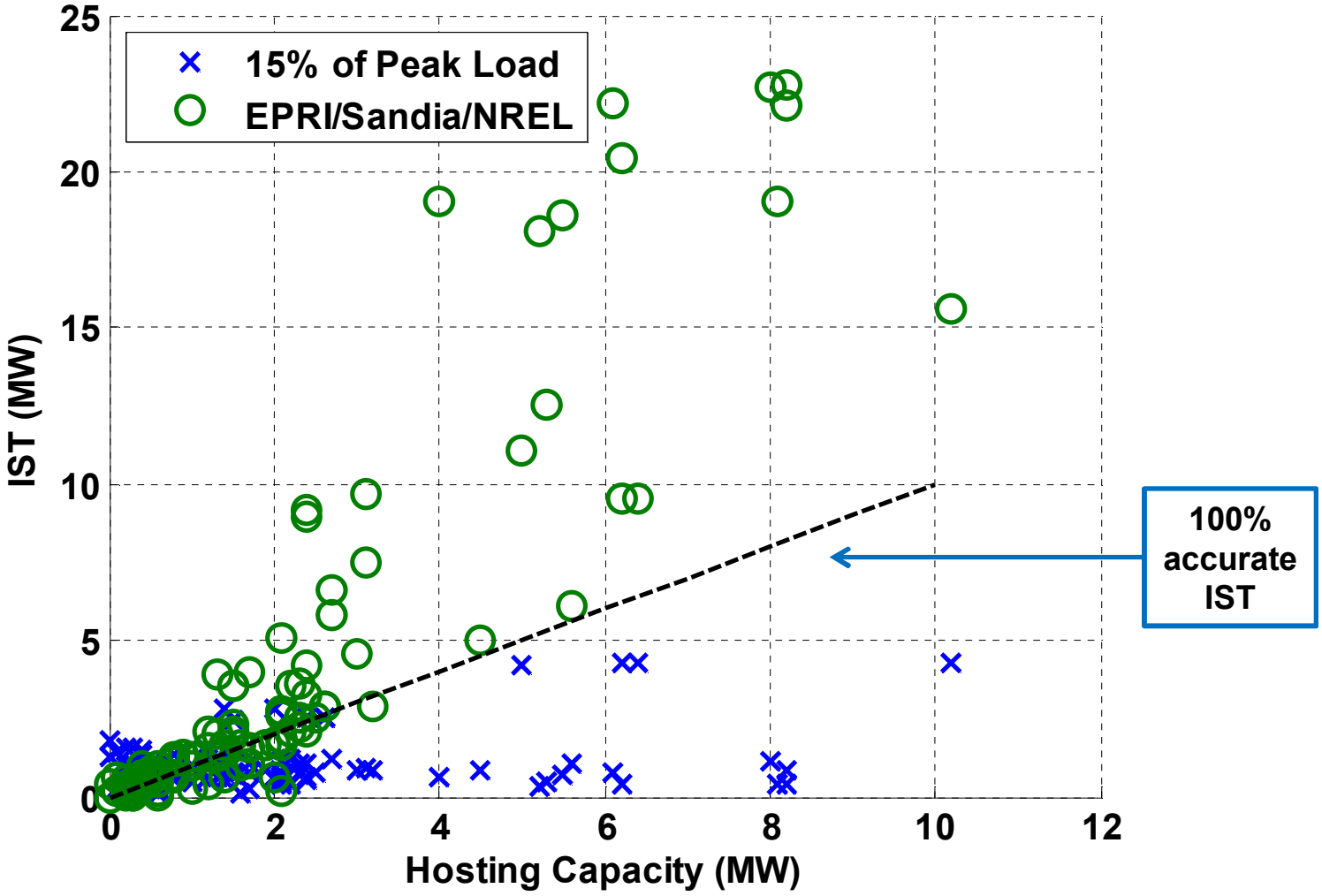


15% screen allowing interconnects that can potentially cause problems.

Feeder hosting capacity vs Interconnection screening threshold (IST) for 3 methods



Feeder hosting capacity vs new method developed by EPRI, SNL and NREL.



Screening analysis summary

- Since PV hosting capacity on a feeder is not well correlated with the feeder load, the 15% screen is very inaccurate.
- The accuracy of the minimum daytime load screen and the FERC fast track threshold screen is better than the 15% screen but each screen is not well correlated with the PV hosting capacity.
- The EPRI/SNL/NREL screen has the lowest percent error, but still incorrectly allowing some very large PV interconnections.
- Screening is very difficult to do both simply and accurately for all cases.

Clustering as a Method to Group Feeders by PV Hosting Capacity

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- As PV penetration continues to increase, utilities are concerned about the impact that these systems will have on the distribution system.
- Gathering the data and creating feeder models that accurately predict the impact of PV systems on the distribution feeder is a difficult and tedious process.
- Recently, data clustering techniques for grouping distribution feeders with similar characteristics have been proposed for simplifying the PV interconnection process by creating hosting capacity maps for entire service areas.

Clustering and Hosting Capacity maps

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Utility Service Territory

Data for all distribution feeders (3000+)

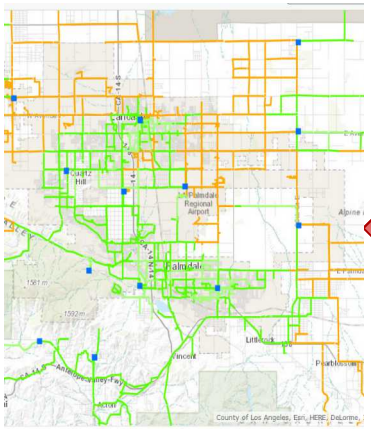
Cluster the feeders into groups (~30)

Identify representative feeder for each group

Detailed studies to determine hosting capacity for each representative feeder

Assign hosting capacity values to the rest of the feeders in each cluster to create a hosting capacity map for service territory

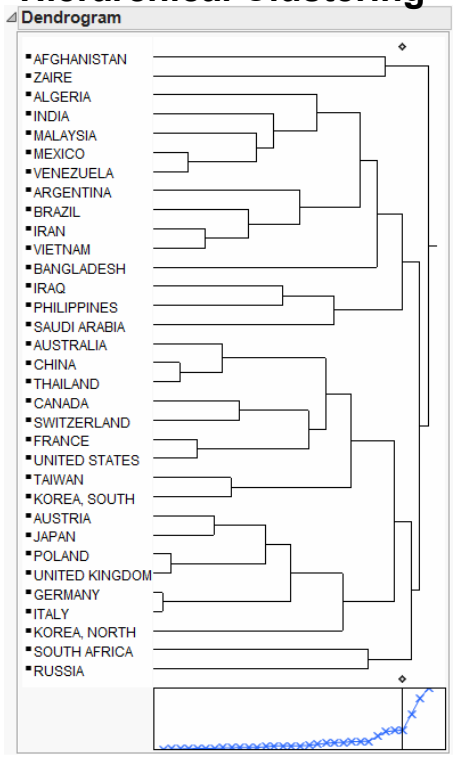
Hosting Capacity Map



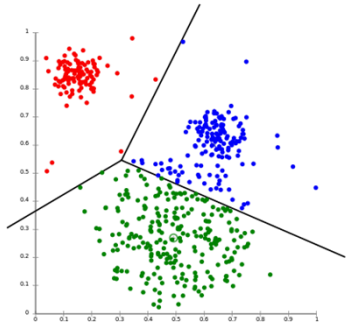
Clustering Methods

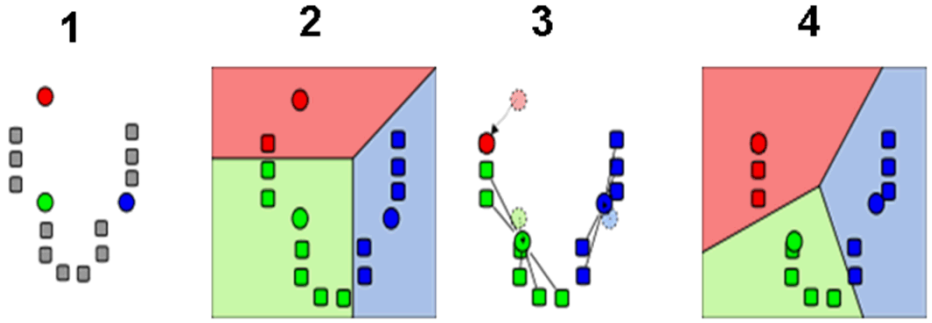
- Use statistical analysis to study utilities distribution feeders. We want to place feeders into specific groups, driven by feeder properties, so that feeders in one cluster are similar to each other, and dissimilar from feeders in other clusters.
- Common methods for clustering include hierarchical and k-means. The k-means method was chosen due to its advantage in clustering with larger data sets.

- **Hierarchical Clustering**



- **K-Mean Clustering**





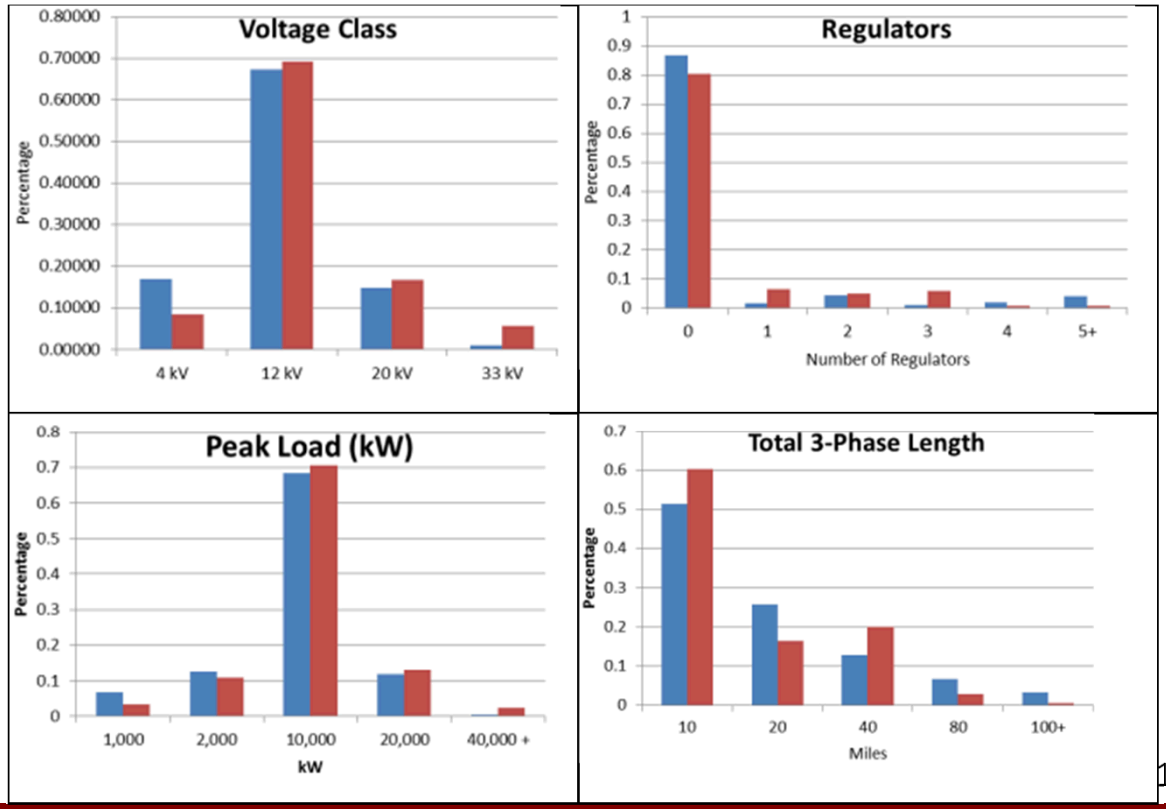
Study Data

Hosting capacity results for 214 study feeders are used to predict a range of hosting capacities for an additional 7929 feeders using clustering techniques.

Example utility feeder data

Feeder Topology	Primary Voltage Type of Feeder Total 3PH Miles OH 3PH Miles Total 1&2PH Miles OH 1&2PH Miles
Voltage Control	Regulators Capacitors Boosters Stepdowns
Protection	SCADA Breaker Fuses Reclosers Sectionalizers Interrupters
Customer Info	# Dom Cust # Com Cust # Ind Cust # Agr Cust Other Customer Total Customers
Load and Capacity Info	Transformer Count Summer Peak kW Summer KVA Capability Winter Peak KW Winter KVA Capability
DG and PV Data	DG kW PV kW # of DG # of PV 0-20kW PV 20-200kW PV >200kW PV kW DG as % of Max Feeder Kw kW PV as % of Max Feeder Kw

Feeder characteristics for full set of 8143 feeders (Blue) and 214 study feeders (Red)



Clustering Process

1. ***Selecting Variables for Clustering***

   The clustering was performed using 8 feeder characteristic variables with a double weighting on feeder primary voltage. The other feeder variables were: Total 3-Phase miles, Total 1 & 2 Phase miles, Residential Customer %, Regulator #, Capacitor # and feeder peak load. These variables are typically easy for utilities to determine and were available for each of the 8,143 feeders.

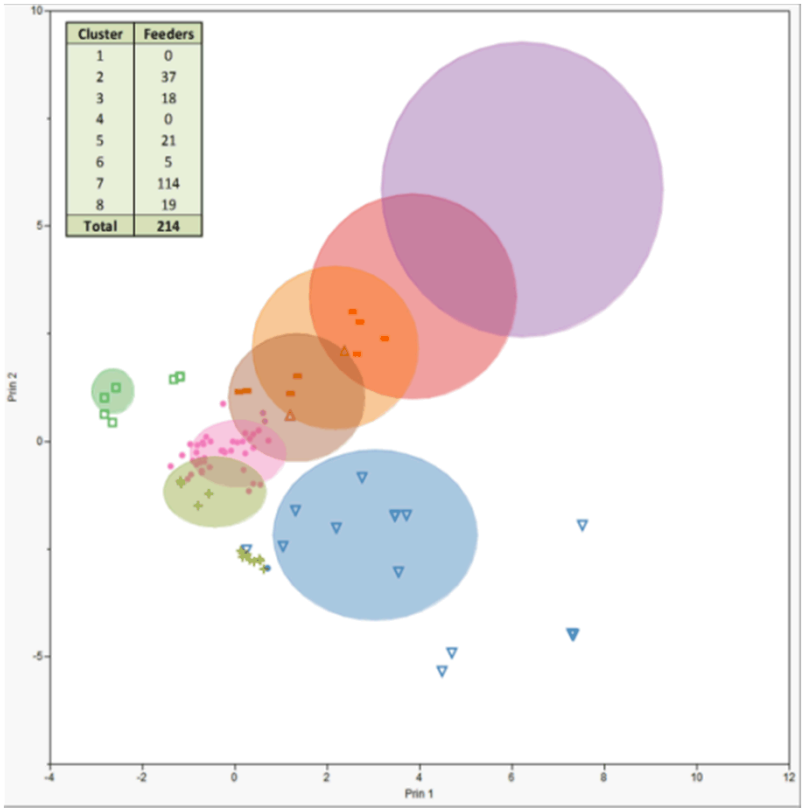
2. ***Removing Outliers***

   Feeders labeled as outliers are those that are not representative of the overall data set. K-means clustering algorithms can be very sensitive to outliers, especially if the initial cluster means are chosen based on the outliers.

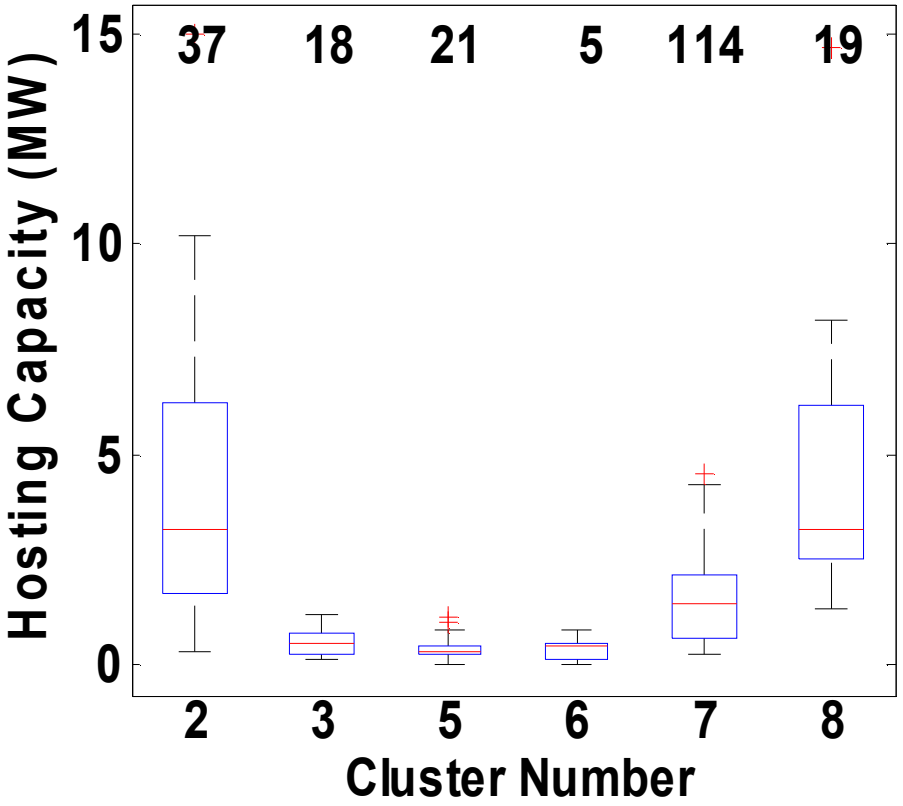
3. ***Cubic Clustering Criterion***

   The optimum number of clusters can be derived from a cubic clustering criterion value based on minimizing the within-cluster sum of squares.

Clustering Results

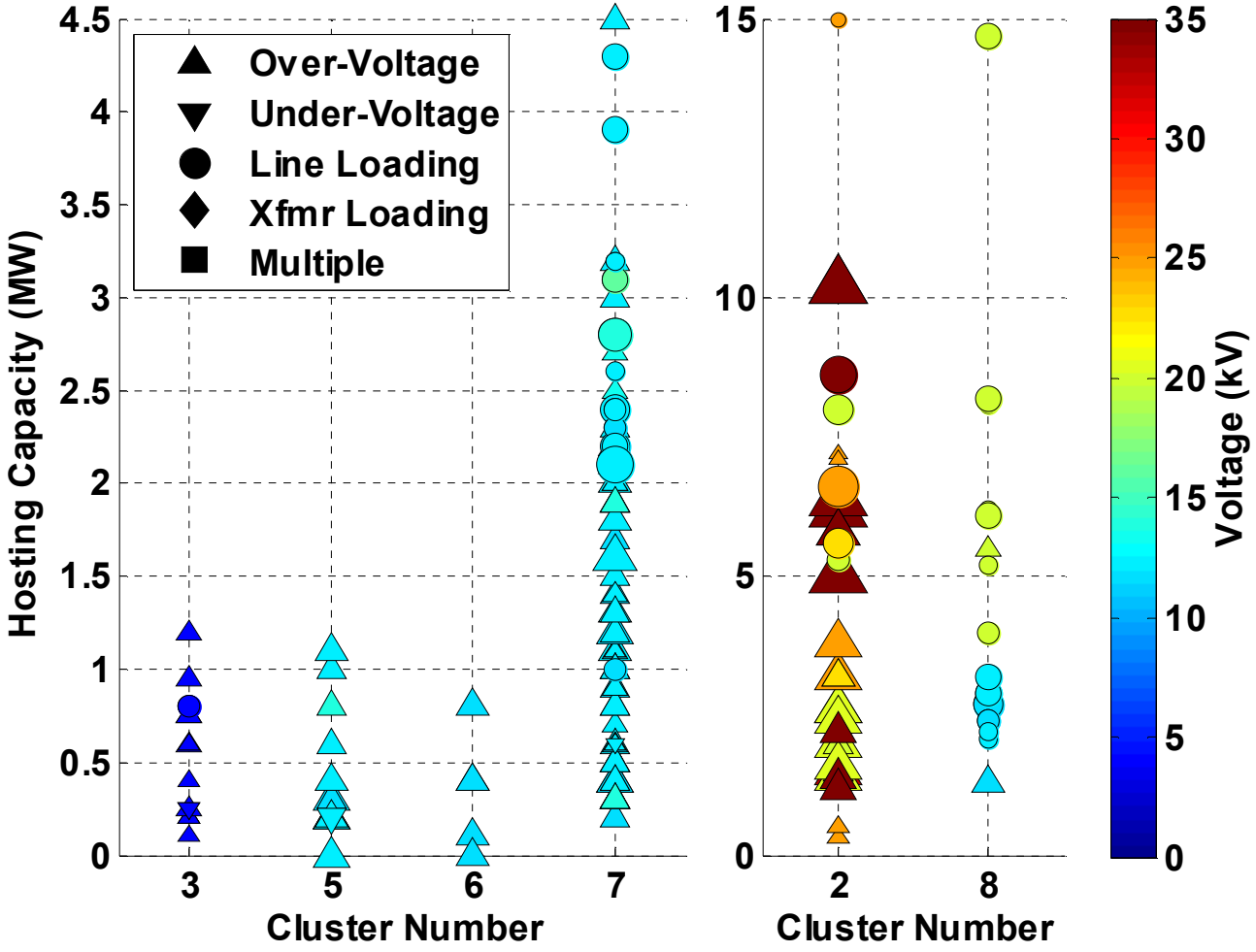


Biplot of the 8 cluster solution for 8,143 feeders with 214 study feeders shown by markers



Boxplot of 6 clusters showing the range of hosting capacities for the study feeders (Ignoring clusters with 3 or less study feeders)

Cluster Results



Hosting capacity violation type shown by marker shape for each feeder in the same 6 clusters.

VARIATIONS IN CLUSTERING METHODOLOGY

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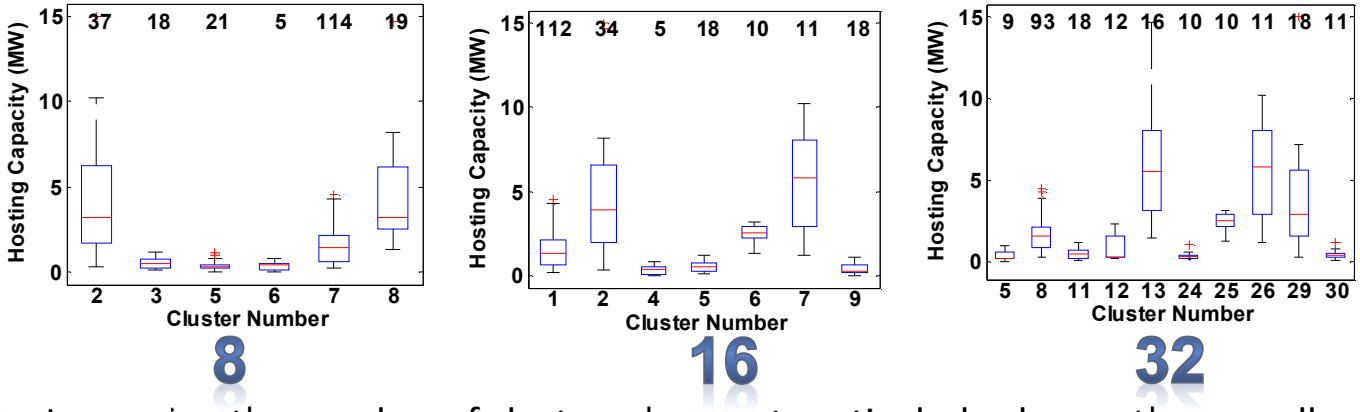
Dependence of HC Accuracy on Number of Clusters



- Increasing the number of clusters does not particularly change the overall accuracy of the clustering solution

Dependence of HC Accuracy on Weighting of key cluster variables

Variable	Correlation Factor (|CF|)	Weighting
Primary Voltage (kV)	0.6	4X
Total 3-Phase Conductor (miles)	0.33	2X
Total 1 & 2 Phase Conductor (miles)	0.1	1X
Residential Customers (%)	0.33	1X
Number of Regulators	0.28	1X
Number of Capacitors	0.19	1X
Feeder Peak Load (kW)	0.31	2X

- Result: The average variation in hosting capacity for each cluster ranged from 77% to 106% of the mean hosting capacity of that cluster

- The weighting of the initial variables did improve the overall accuracy in two cases, but the range in hosting capacity variation is still very high even in the best case.

Conclusions

- The accuracy of clustering as a method to group distribution feeders into specific ranges of PV hosting capacity has been shown to be relatively inaccurate.
- Clustering is still useful as it provides good separation between clusters in many cases, but it has its limitations.
- The best clustering solutions for the various methods explored did not predict the hosting capacity accurately and the best solution had an average hosting capacity variation of 77%.
- Clustering will never perfectly group feeders such that all unique characteristics match with a single PV hosting capacity for the feeder, but it can provide a rough estimate of the hosting capacity for similar types of feeders.

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QUESTIONS?

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