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# Distributed Generation Integration Study Workshop: Analytical Framework

*Presentation of Interim Results*

California Energy Commission
Sacramento, California

August 22, 2013



DISPUTES & INVESTIGATIONS • ECONOMICS • FINANCIAL ADVISORY • MANAGEMENT CONSULTING

# Today's Agenda

1 » CEC Program Objectives and Scope

2 » Analytical Framework

3 » Study Assumptions

4 » Feeder Selection and Modeling

5 » DG Integration Analysis

6 » Interim Study Results

7 » Next Steps

8 » Questions and Answers





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# Project Overview:

## » Background

- Governor's Clean Energy Jobs Plan: 12,000 MW of localized renewable energy
  - 20 MW or less
  - On-site or close to load
  - Constructed quickly w/ no new transmission
- Southern California Edison Study
  - Many interconnection requests do not align with preferred DG policy definition
  - 4,800 MW T&D integrations cost:
    - Unguided Case: up to $4.5 billion
    - Guided Case: ~ $2.1 billion

## » For Consideration

- Should the state guide DG development?
- If yes, is the framework presented today a viable option?
- How could this framework, or something like it, be utilized?
- What regulatory process(es) could this study inform?

## » Study Purpose

- Gain a better understanding of infrastructure costs and impacts associated with increased DG installations in California, and how they change based on interconnection location, distribution feeder characteristics, load types, and project size.
- Develop a framework for a DG planning tool

## The addition of up to 12,000 MW of renewable DG is expected to transform electric grid operations and impose additional costs

*. . . Accurate tools are needed to predict impacts and upgrades needed to ensure successful integration of renewable DG*

" As variable and distributed energy resource adoption reach significant levels this decade, new engineering and operating paradigms are required.

Resnick Institute, CalTech, Sept, 2012, *Grid 2020 Towards a Policy of Renewable and Distributed Energy Resources.*

"Estimates for fully capable distribution circuits suggest an additional cost of between $2 million and $3.5 million per circuit for physical upgrade and intelligent control systems."

Electric Power Research Institute. April, 2011. *Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid.*

***Despite the sophistication of currently available simulation models and tools, models that can simultaneously evaluate and optimize the integration of widely distributed, intermittent generation have not been developed***

***The methods and tools applied in the CEC framework are designed to predict DG impacts and integration costs with reasonable accuracy, and applicable for use by California utilities and stakeholders***





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# A Project Advisory Committee comprised or representatives from the state's largest utilities has provided valuable input into the process

## » PAC Objectives

- The CEC sought PAC input into the study framework
- Provides a suggested guideline and analytical method that utilities can use to evaluate DG impacts and integration costs
- Hosted a review and discussion on July 31 with utilities about method developed and applied to SCE's system to better understand DG penetration potential and integration costs

## » CEC Program Objectives

- Renewable DG goal of 12,000 MW by 2020
- Generate cost inputs to renewables programs so CPUC can decide what programs to expand or adjust and to inform policy recommendations
- Inform development of incentives or guidelines that fall within CEC renewables programs

**Questions addressed by the PAC:**

1. **Are there data or methods that CEC should consider for the framework?**
2. **Are the data and methods used appropriate for the goal? If not, what would be more appropriate?**
3. **Do other utilities have the capabilities or data described in this framework?**

# The CEC DG Integration study builds upon work previously completed by SCE in 2012

» Study seeks to determine how DG integration costs vary based on:

- Amount of installed DG capacity
- Size
- Type/technology
- Location

» Key results from SCE's May 2012 report*

- Integration costs vary significantly according to location (e.g., urban versus rural)
- T&D integration cost ranged from $4.5 billion for 4,800 MW of DG in the "Unguided Case" versus $2.1 billion for "guided" case

» CEC study expands upon SCE's analysis

- Increases number of distribution feeders modeled
- Varies key assumptions and related parameters for DG installed across the SCE system
- Similar to SCE study, analysis excludes DG benefits, MicroGrids, and bulk power system impacts

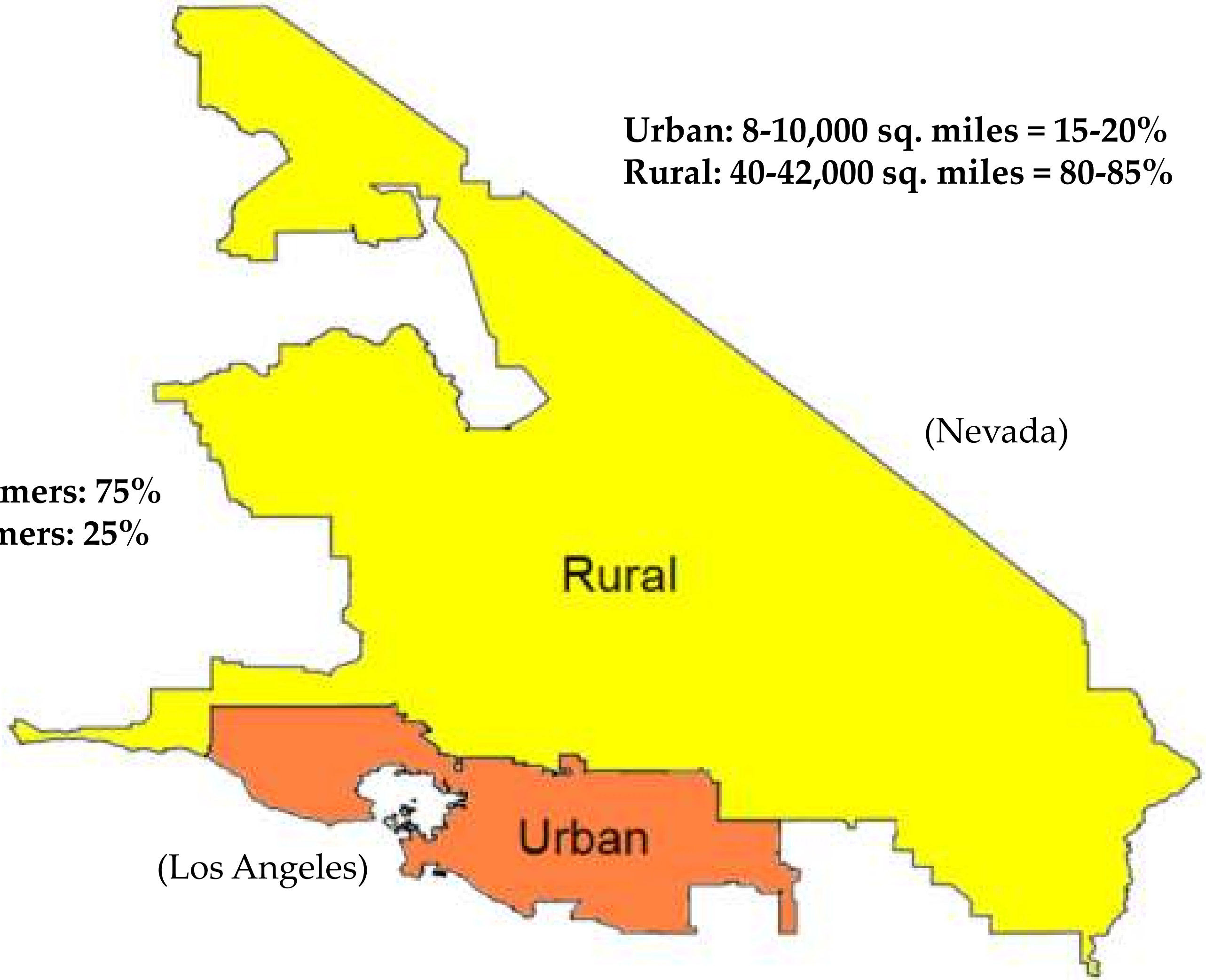
* *The Impact of Localized Energy Resources on Southern California Edison's Transmission and Distribution System*

***Results are high level and not a substitute for detailed interconnection analysis for individual DG interconnection requests***

# Many of the preferred locations for DG are located in high load density urban areas, where distribution feeders typically are shorter

**Urban: 8-10,000 sq. miles = 15-20%**
**Rural: 40-42,000 sq. miles = 80-85%**

**Urban Customers: 75%**
**Rural Customers: 25%**





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# The project is scheduled to be completed later this summer, pending today's review and finalization of study results

**Scope**

- Identify cost to integrate up to 12,000 MW of renewable DG* in California
- Establish an analytical framework for use by other utilities
- Analyze impact and associated costs of integrating a proportional amount of DG in SCE's service territory

**January 2013**

- Establish framework objectives: Build upon previous DGPV studies by E3 and SCE
- Prepare design/study comparison framework

**Spring/Summer 2013**

- Develop distribution models with SCE
- Forecast CA PV costs Perform DG integration analysis
- Identify distribution upgrades

**July 2013**

- Review analytical framework with Project Advisory Committee (July 30)
- Incorporate PAC feedback into framework & analysis

**August/Fall 2013**

- CEC Workshop (August 22) – Review framework and interim results
- Review and revision of Navigant report and results

*Also referred to as Local Energy Resources (LER)





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# The analytical framework presented today is designed to be applicable to electric utility distribution systems throughout California

## The framework is designed to contain the following features:

1. Has clear and easy to follow methods and assumptions
2. Contains sufficient analytical rigor to produce accurate results
3. Applies models and tools that are commonly used to simulate utility system operations
4. Uses processes that are understandable and repeatable for different scenarios
5. Includes Renewable DG technologies available to all California utilities and consumers
6. Uses evaluation criterion consistent with common industry practices and standards
7. Is expandable to include new DG technologies or solutions to address constraints
8. Produces results that clearly identifies all DG impacts and costs

***Others applying the framework are expected to introduce features, options and assumptions that may be unique to their respective systems***





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# The framework includes a series of analysis designed to calculate DG integration costs for a range of DG scenarios

(1) Identify the type and capacity of applicable DG technologies by location

(2) Select a set of distribution feeders to represent the entire system

(3) Conduct distribution feeder simulation analyses for DG integration scenarios

(4) Identify system impacts that require mitigation

(5) Select mitigation options or solution to address distribution violations and constraints

(6) Estimate transmission impacts (based on CAISO Resource Availability studies)

(7) Calculate DG integration costs (transmission and distribution), including interconnection

(8) Conduct parametric studies for key assumptions

DG Integration Costs





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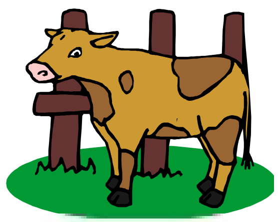
# Study assumptions are based on those applicable to the SCE system – the amount and type of DG installed will vary by utility and by region



**Distributed Generation**

- 90% PV
- 10% biomass
- All currently available technology

| | |
|---|---|
| Renewable DG 2020 Target (CA Clean Energy Plan) | 12,000 MW |
| SCE Baseline DG Penetration (2012 SCE Study) | 4,800 MW |
| SCE Maximum DG Penetration (25% over baseline) | 6,000 MW |
| SCE Minimum DG Penetration (50% below baseline) | 2,400 MW |

# Key study assumptions and guiding principles have been established for the analytical framework (slide 1 of 2)

» Feeder selection
- Based on clustering approach (mathematical model)
- Mix of rural and urban feeders representative of the entire SCE distribution system

» Integration costs
- Interconnection costs based on historical cost estimates (SCE)
- Per unit cost of mitigation/upgrades based on prior SCE impact studies & Navigant data
- Navigant prepared estimates where upgrades have not been previously analyzed

» Technology options
- Mitigation options/upgrades based on currently available technology
- Near-term advanced technologies and solutions are considered (Smart Grid)
- Energy storage is an option to enable DG integration

» IEEE 1547 Standards/Guidelines*
- Based on requirements as of January 1, 2013
- Includes series of standards under 1547, where applicable

» Simulation approach
- Commercially available load flow model, validated by SCE team
- Static load flow model
- Additional analysis to for operational impacts not fully addressed in simulation studies

» DG costs
- Navigant best estimates, varies by CA locale
- Not addressed in today's framework review

» Largest single DG unit is 20 MW
- Most DG ≤ 10 MW because most feeders are rated ≤ 10 MW

* IEEE Std 1547TM(2003)Standard for Interconnecting Distributed Resources with Electric Power Systems





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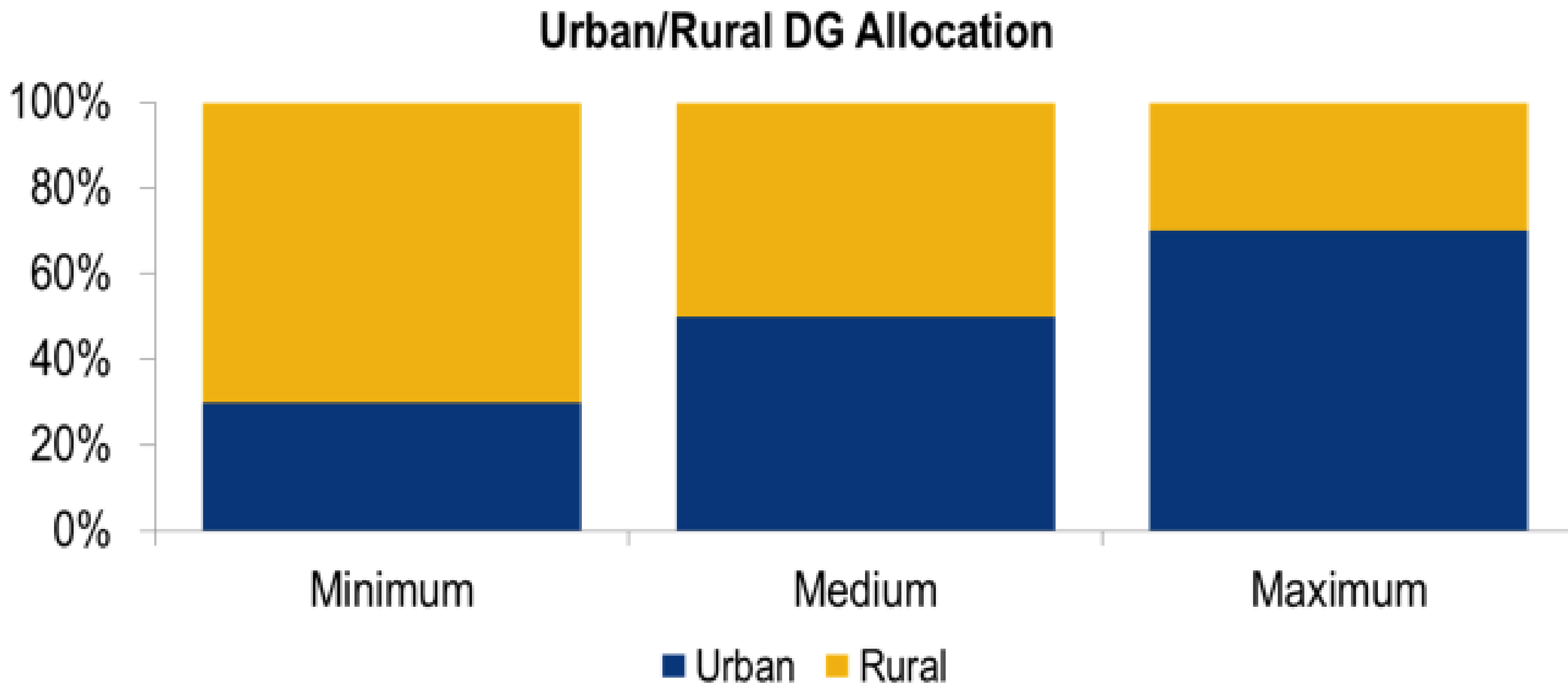
## Study Assumptions (slide 2 of 2)

- System benefits not included in the evaluation
  - E3 is evaluating benefits in its update of the CPUC DG Potential Study
- Conservation Voltage Reduction (CVR) not applied
  - Widespread implementation of CVR would reduce amount of DG that can be installed or require system upgrades
- PV intermittency based on local changes (e.g., cloud cover)
  - Area-wide changes in PV output not included, but may be applicable to other systems
- Integration costs include DG interconnection and distribution system upgrades
- DG interconnects to 33 kV, 16kV, 12 kV, and 4 kV feeders
  - Interconnection at higher voltage lines not considered as they used to interconnection generation above the 20 MW limit (CA Clean Energy Plan & IEEE 1547 definition for DG)
- Transmission impacts are locational and based on CAISO Transmission Resource Plans and DG Resource Adequacy studies

# DG Characterization & integration scenarios include a mix mostly urban, mostly rural and equal amounts of DG in each region

*These cases also are described as Guided (Maximum urban), Unguided (Maximum Rural), and Hybrid*



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## An analytical approach is used to select a subset of distribution feeders to accurately represent the entire SCE system for DG modeling

- Navigant selected a subset of feeders that are representative of the entire SCE system (~ 4,000 feeders)
- Analytical approach similar to SCE selection method for its May 2012 study
  - Feeder selection based on a statistical "clustering" technique to group feeders according to the following attributes:
    - Urban and rural location
    - Lower voltage (4.16 kV) versus higher voltage feeders (12.47/16/33 kV)
    - Short and long feeders
    - Primarily residential versus primarily commercial/industrial customers
    - Light and heavy load density
- This set of feeders used to simulate DG impacts given differences in:
  - Feeder attributes
  - Location
  - Feeder loadings





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# Feeder Selection Process - Overview

## Objective:

» Collect and analyze data on all distribution feeders (~4,000 )from SCE, covering approximately 30 different attributes, such as customer counts, loading, energy usage by rate class, line length, existing DG, etc.

» Goal is to identify a manageable set of feeders obtained from a 'cluster' of similar feeders, any of which can be represented by a single feeder

– SCE's study examined four representative feeders (Urban 4 kV, Urban 12 kV, Rural 4 kV, Rural 12 kV). The CEC study expanded this to ~12 feeders to increase the resolution of the assessment

## Process:

1. Selected nine key attributes, and used a computer algorithm to determine the similarity between feeders across these attributes (detailed on following slides). The algorithm grouped feeders into 'clusters', each of which had unique characteristics.

2. Next, examined the resulting clusters, and settled on a group of ~12 to broadly represent the entire SCE distribution system.

3. An "average" feeder from each cluster was chosen to represent a population of comparable feeder for DG integration studies.





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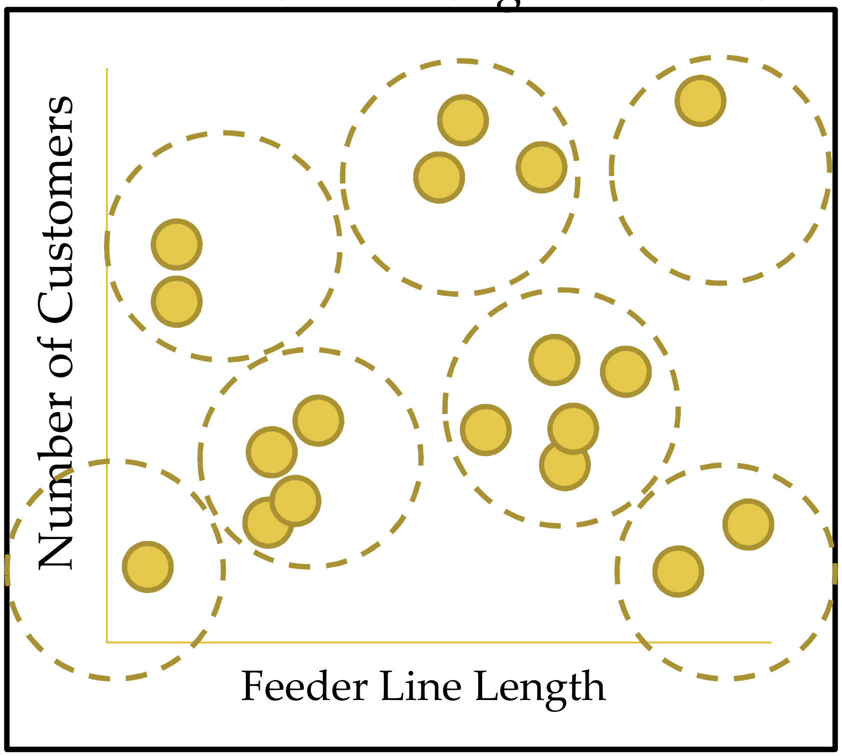
# Feeder Selection Process – Determining Similarity (“Distance”)

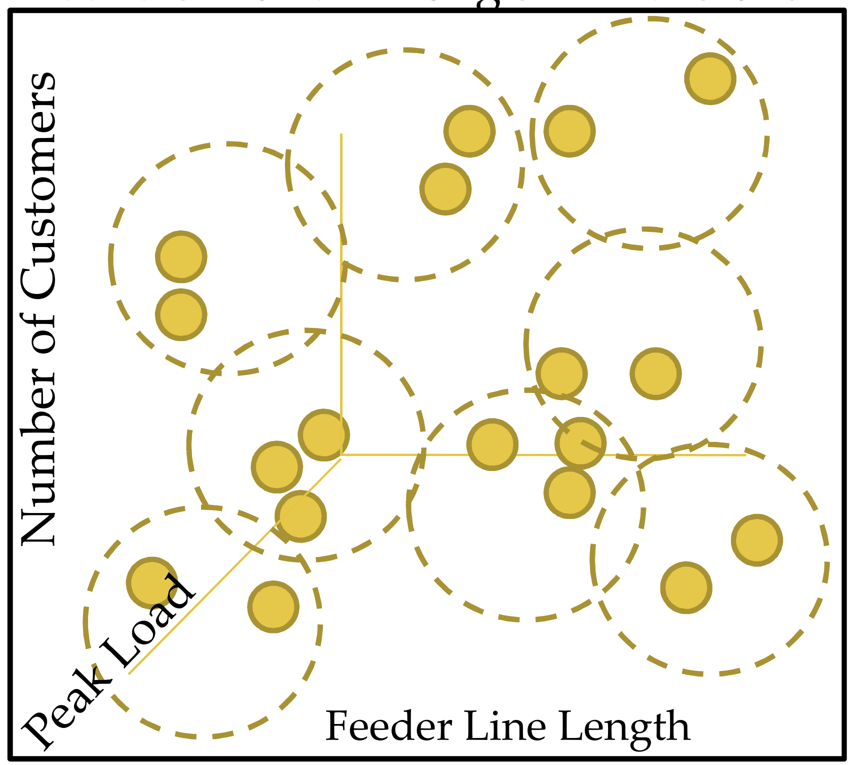
***Spatial distance between two feeders along a set of attributes determines the similarity of those feeders along those attributes***

- Diagram shows feeders (represented by dots) plotted first in two dimensions, then three. Adding the third attribute allows for greater distinction to be made between feeders.
- We calculated the distance between every feeder across nine attributes. This gave an indication of which feeders were most similar to each other – the lower the distance, the more similar the feeders

Feeders Plotted Along 2 Dimensions




Feeders Plotted Along 3 Dimensions





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# Feeder Selection Process – Clustering Algorithm

» Once the similarity between each feeder was calculated, a simple algorithm was developed to group the feeders into clusters

1) The first feeder initiates a new cluster
2) The next feeder in the list is compared to all the existing clusters. If it is sufficiently similar to an existing cluster, it is grouped in that cluster. Otherwise, it initiates a new cluster of its own.
3) Step 2 is repeated until all feeders are assigned a cluster.

» The only variable that must be specified is a threshold distance in order to consider two feeders sufficiently similar.

- If the threshold distance is large (relaxed definition of similarity), the result will be fewer clusters, each with many feeders.
- If the threshold distance is small (stricter definition of similarity), the result will be more clusters, each with fewer feeders.

Once





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# Feeder Selection Process – Sample Clustering and Conclusions

» Table below is an example of the clustering methodology. It contains the ten most similar feeders for nine attributes highlighted in **bold**. All feeders are urban.

» The feeders are very similar, any one could be used to represent the entire cluster

- The full clustering process involves grouping hundreds of feeders, so there is necessarily wider variance along each attribute
- However, clusters are mathematically distinct; together they provide increased resolution for analysis of SCE's distribution system

| **Commercial Customers** | **Domestic Customers** | Idle Customers | Industrial Customers | Other Customers | **Nominal voltage, kV** | **Total 3-ph ckt miles, mi** | **Total 2-ph and 1-ph ckt miles, mi** | **Feeder peak load, AMPS** | Feeder peak load, kVA (calculated) | kVA/customer | **Residential, %** | **Commercial, %** | Industrial, % | Agricultural, % | Total amount of DG on circuit, kW | Existing PV capacity installed, kW | Urban/Rural Binary |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 565 | 0 | 0 | 1 | 4.16 | 3.1 | 2.6 | 330 | 2379 | 4.1 | 98% | 2% | 0% | 0% | 25 | 25 | 1 |
| 13 | 502 | 2 | 0 | 0 | 4.16 | 3.4 | 2.6 | 334 | 2408 | 4.7 | 98% | 2% | 0% | 0% | 18 | 18 | 1 |
| 11 | 559 | 1 | 0 | 1 | 4.16 | 3.3 | 2.5 | 337 | 2425 | 4.2 | 97% | 3% | 0% | 0% | 6 | 6 | 1 |
| 4 | 546 | 0 | 0 | 1 | 4.16 | 2.8 | 2.7 | 339 | 2441 | 4.4 | 99% | 1% | 0% | 0% | 28 | 28 | 1 |
| 22 | 678 | 0 | 0 | 0 | 4.16 | 2.8 | 2.3 | 329 | 2367 | 3.4 | 99% | 1% | 0% | 0% | 11 | 11 | 1 |
| 16 | 632 | 2 | 0 | 0 | 4.16 | 3.4 | 3.4 | 331 | 2387 | 3.7 | 97% | 3% | 0% | 0% | 10 | 10 | 1 |
| 6 | 528 | 0 | 0 | 1 | 4.16 | 2.6 | 2.7 | 314 | 2265 | 4.2 | 99% | 1% | 0% | 0% | 17 | 17 | 1 |
| 10 | 518 | 0 | 0 | 1 | 4.16 | 2.9 | 2.7 | 312 | 2246 | 4.2 | 97% | 3% | 0% | 0% | 25 | 25 | 1 |
| 8 | 497 | 4 | 0 | 3 | 4.16 | 3.9 | 4.4 | 319 | 2301 | 4.5 | 98% | 2% | 0% | 0% | 76 | 76 | 1 |
| 8 | 590 | 0 | 0 | 1 | 4.16 | 3.7 | 4.0 | 318 | 2289 | 3.8 | 100% | 1% | 0% | 0% | 36 | 36 | 1 |





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# The analysis resulted in the selection of 13 feeders to represent the entire SCE system, which has approximately 4,000 distribution feeders

» The final threshold distance resulted in 48 distinct clusters. Of these, 28 contained at least 10 feeders - taken together, these represent over 98% of SCE's feeder population

» List then was reduced to 13 by combining sufficiently similar clusters, eliminating clusters that were did not provide additional resolution, etc.

» The resulting list of clusters (and number of feeders in each cluster) is shown below.

| 7 Urban classifications | 6 Rural classifications |
|---|---|
| 1. Urban ~4 kV (788 feeders)<br>2. Urban 12-16 kV Residential (536 feeders)<br>3. Urban 12-16 kV Commercial (397 feeders)<br>4. Urban 12-16 kV Industrial (332 feeders)<br>5. Urban 12-16 kV Residential-Commercial (1,160 feeders)<br>6. Urban 12-16 kV Long (20 feeders)<br>7. Urban 33 kV (13 feeders) | 1. Rural ~4kV (82 feeders)<br>2. Rural 12-16 kV Short (147 feeders)<br>3. Rural 12-16 kV Medium (269 feeders)<br>4. Rural 12-16 kV Long (55 feeders)<br>5. Rural 12-16 kV Agricultural (65 feeders)<br>6. Rural 33 kV feeders (12 feeders) |

***Many urban feeders have similar characteristics and attributes . . . Urban Feeder 1 represents 788 urban feeders, whereas Rural Feeder 6 represents 12 feeders***





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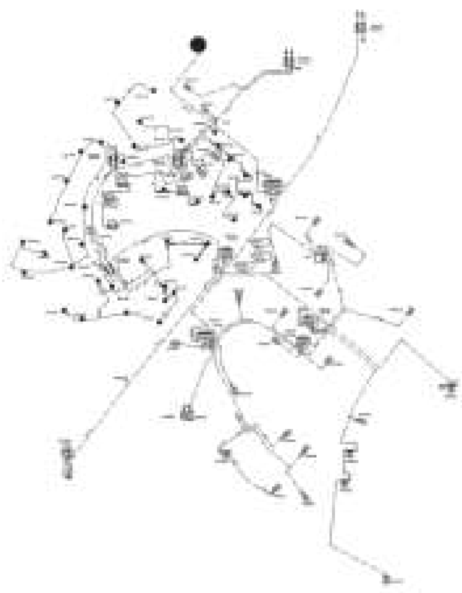
# Feeder Selection Process – Detailed feeder attributes, loads and customer data outlined below (includes 4 feeders from SCE study)

| Feeder | Rural / Urban | Fdrs Represented | Total Customers | Voltage (kV) | Line Miles | Peak Load (kVA) | Residential (Percent) | Commercial (Percent) | Industrial (Percent) | Agricultural (Percent) | Existing DG(kW) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feeder 1 | urban | 788 | 770 | 4.16 | 5.9 | 1780 | 87% | 12% | 0% | 0% | 122 |
| Feeder 2 | urban | 536 | 1972 | 12 | 19.6 | 10981 | 97% | 2% | 1% | 0% | 0 |
| Feeder 3 | urban | 397 | 346 | 12 | 7.4 | 6793 | 0% | 91% | 10% | 0% | 56 |
| Feeder 4 | urban | 332 | 23 | 12 | 5.2 | 12985 | 0% | 6% | 90% | 5% | 0 |
| Feeder 5 | urban | 1160 | 1557 | 12 | 14.2 | 9327 | 28% | 59% | 13% | 0% | 305 |
| Feeder 6 | urban | 20 | 1302 | 16 | 51.8 | 5949 | 28% | 48% | 0% | 24% | 264 |
| Feeder 7 | urban | 13 | 1 | 33 | 18.5 | 10631 | 0% | 0% | 0% | 100% | 0 |
| Feeder 8 | rural | 82 | 573 | 4.8 | 3.7 | 2102 | 86% | 15% | 0% | 0% | 10 |
| Feeder 9 | rural | 147 | 701 | 12 | 12.0 | 7509 | 20% | 81% | 0% | 0% | 234 |
| Feeder 10 | rural | 269 | 430 | 12 | 13.8 | 1820 | 43% | 52% | 0% | 5% | 48 |
| Feeder 11 | rural | 55 | 721 | 12 | 68.5 | 2897 | 44% | 17% | 0% | 39% | 33 |
| Feeder 12 | rural | 65 | 468 | 12 | 35.4 | 6610 | 4% | 1% | 0% | 94% | 0 |
| Feeder 13 | rural | 12 | 6 | 33 | 15.6 | 10003 | 0% | 0% | 0% | 100% | 0 |

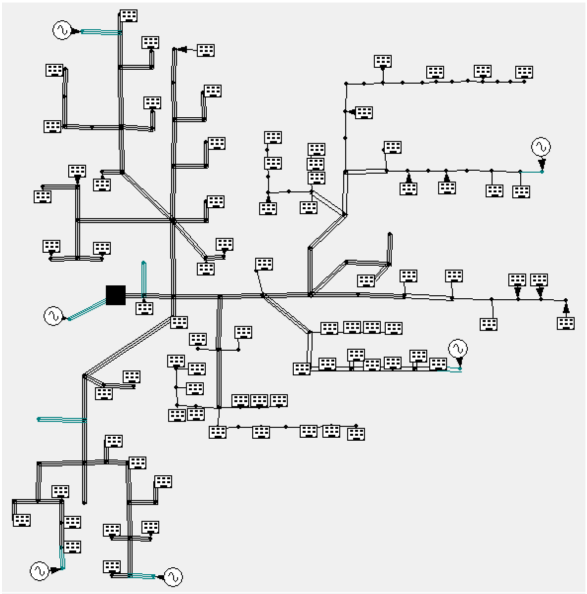
The number of feeders represented by urban circuits is significantly higher than rural, as they have greater uniformity and similar attributes

# Accurate simulation requires use of distribution load flow models. Many commercially available software packages are suitable

*Navigant uses Milsoft's Windmil load flow model*

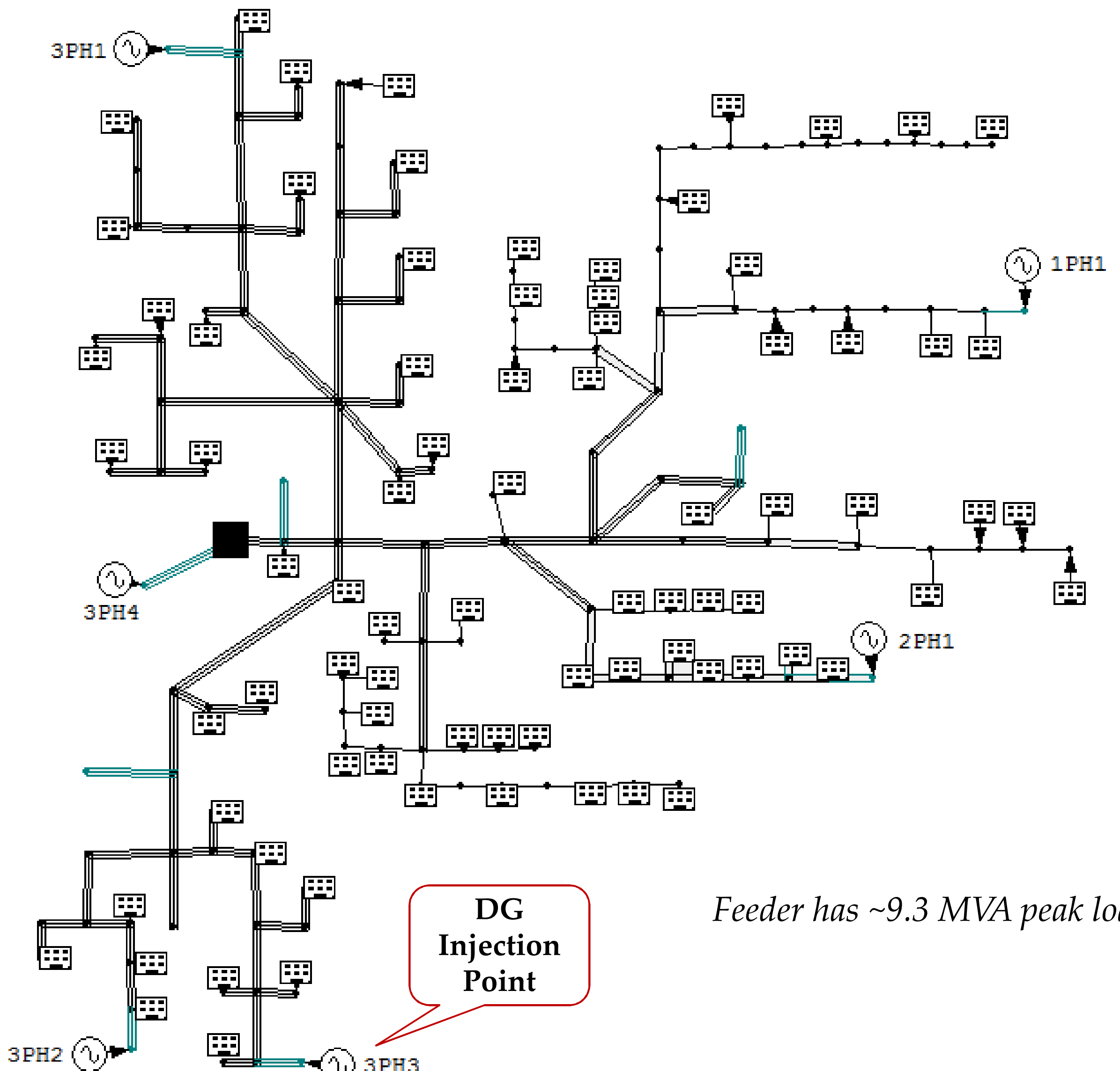


Map of feeder before simplification for modeling. The feeders may be complex, representing many branches, tie-ins, and multiple loadings.



Milsoft load flow model (not to scale), cross-checked with SCE's model to ensure accuracy before evaluating integration scenarios.

# Example: Model translation – Urban 12 kV




- Representation of 12 kV urban feeder – Not to scale. Line lengths are defined separately.
- DG injection sites at the ends of 3-phase laterals (top-left, bottom-left corners) and at the substation. [3PH1, 3PH2, 3PH3, 3PH4]
- Additional DG sites at the ends of 1- and 2-phase laterals (center-right). [1PH1, 2PH1]

*Feeder has ~9.3 MVA peak load, and ~300 kW of existing PV*





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# The number of DG injection points is based on DG size, capacity and type; feeder length and customer mix also are important factors

**Residential**
- 4-10 Injection points
- Minimum 10 kW
- Medium 15 kW
- Maximum 25 kW

**Commercial**
- 1-4 Injection points
- Minimum 15 kW
- Medium 100 kW
- Maximum 1-5 MW

**Ground based**
- 1-2 Injection points
- Minimum 50 kW
- Medium 500 kW
- Maximum 10 MW

***Residential DG is "clustered" at several injection points on the feeder to facilitate feeder modeling and analysis***

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# The DG integration study includes parametric analysis to determine how integration costs vary as a function of capacity, locations, etc.

*Integration costs include: (1) interconnection & (2) distribution system upgrades*

## Methodology:

1. Calculate cost of DG interconnection cost, distribution system upgrades, and bulk transmission cost (CAISO) for each case study
2. Estimate cost to install up to 4,800 MW of DG on SCE's distribution system under range of integration scenarios based on case study results
3. Account for variation in integration costs
    - Location (e.g., urban versus rural)
    - DG type and size
    - Clustered (on different segments of a feeder)
    - As a function of the amount of installed DG

# **Performance standards used to evaluate DG impacts are based on <u>current</u> industry standards, SCE planning guidelines and Rule 21.**

## ***DG interconnection requirements adopted for this study include:***

1. DG is considered non-firm and does not provide feeder capacity support
2. DG output cannot exceed main line or lateral loading limits (load cannot offset DG output)
3. DG is assumed off-line for up to 5 minutes following a circuit interruption (IEEE 1547)
4. Inverter power factor is fixed for the base case; ongoing CPUC/CEC efforts to enhance Rule 21 via active inverter control is considered
5. A material increase in the number of Load Tap Changer (LTC) and regulator operations require upgrades or mitigation
6. Total allowable DG must recognize limits associated with load transfers via feeder ties, either for maintenance of reliability; i.e, cannot exceed feeder loading or voltage limits
7. Any single DG (or small set of large DG units – typically 1 MW or greater) that cause reverse power flow at the substation will interconnect to the subtransmission system

***The impact of intermittent renewable distributed generation on bulk system generation load following and frequency regulation is not addressed in Navigant's study***

# Integration studies addresses impact on feeder voltage performance capacity, operational factors and other potential requirements

## *Additional analysis or data required to supplement feeder load flow studies*

| Category | Description of Constraint or Violation | Load Flow Simulation Required | Supplemental Analysis or Data Required | Additional Requirements |
|---|---|---|---|---|
| Over/Under voltage | Exceeds +/- 5 % from nominal | X | | None |
| Line/equipment overloads | Exceeds normal/emergency ratings | X | X | Equipment ratings or limits not in model database |
| Voltage regulation | Excessive LTC operation | X | X | Detailed (minute-by-minute) PV output |
| Reverse power | Reverse flow on mono-directional equipment | X | X | Equipment list w/o bi-directional capability |
| Fault duty | Exceeds FC ratings | X | X | Fault duty ratings |
| Protection coordination or devices | Changes in settings or new devices | X | X | SCE criterion/requirements |
| Operational constraints | Load transfer constraints (e.g., for maintenance or outage restoration)* | X | X | SCE criterion/requirements |
| Power quality | Voltage flicker | X | X | Detailed (minute-by-minute) PV output |
| Communications & SCADA | Needed for large DG or high penetration DG | | X | SCE criterion/requirements |

** Navigant did not analyze the impact of tie transfers for each feeder, but has adopted this requirement as a general rule. A small number of cases was selected to evaluate the impact of DG following load transfer*





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# Most options for mitigating DG impacts are based mostly on traditional distribution solutions and upgrades

- *Cost of distribution options based on SCE and Navigant estimates*
- *Transmission system impacts & cost based on CAISO study results (PH 2, Q4)*

| | | |
|---|---|---|
| Voltage regulation equipment | Automation / SCADA additions | Overload mitigation (reconductoring) |
| Additional switches and feeder ties | Feeder breaker upgrades | Additional protective devices |
| Protection upgrades | Additional communication / telecom | New distribution lines or substations |

***The applicability of non-traditional, forward-looking solutions such as active PV inverter controls and Smart Grid (Interruptible DG) also is considered.***





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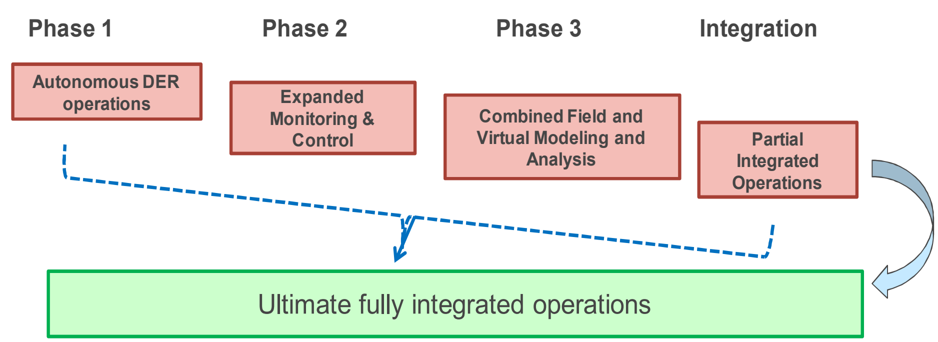
# CPUC/CEC is currently investigating the applicability of Smart Grid systems to manage and optimize DG operations and integration*

The initiative envisions a 4-step process for expanding and enhancing distribution system controls and operations

- The objective is to update technical requirements under Rule 21 to include advanced functionality
- This includes use of DG inverters to supply (or absorb) reactive power for voltage stabilization and control (per IEEE 1547a). *[Smart Inverter Working Group]*
- Advanced (future) applications could include managing DG output during abnormal conditions, such as feeder reconfiguration in response to system interruptions or scheduled maintenance (excerpt from August 2013 draft)

**Phased Approach for Reaching the Ultimate Integration of DER Systems with Utility Operations**




**Phases:**

**1) Start with autonomous DER systems which provide volt/var management, low/high voltage ride-through, responses to frequency anomalies, etc. Use interconnection agreements to ensure appropriate autonomous settings.**

**2) Expand to situational awareness with hierarchical communication networks, monitoring aggregated smaller DER and direct monitoring of larger DER. Issue broadcast requests (pricing signal and/or tariff-based) and/or direct commands**

**3) Combine field and virtual modeling through power flow-based analysis, state estimation, contingency analysis, and other analysis applications to assess economics and reliability.**

**4) Ultimately integrate DER management with distribution automation, load management, and demand response for optimal power system management.**

*Figure 3: Phased approach to integrating DER systems with utility operations*

**Candidate DER Capabilities: Recommendations for Updating Technical Requirements in Rule 21 (August 201 3 Draft)*





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# A sophisticated system architecture, comprised of enhanced communications and controls would enhance DER functionality

- The proposed system includes 4 levels of control, each characterized by increased functionality
- The use of PV inverters to manage reactive output and maintain voltage is outlined in Level 1
- Operational and design issues will need to be addressed via pilots and demonstration projects
- The timing for adopting revised standards for Rule 21 is not yet known

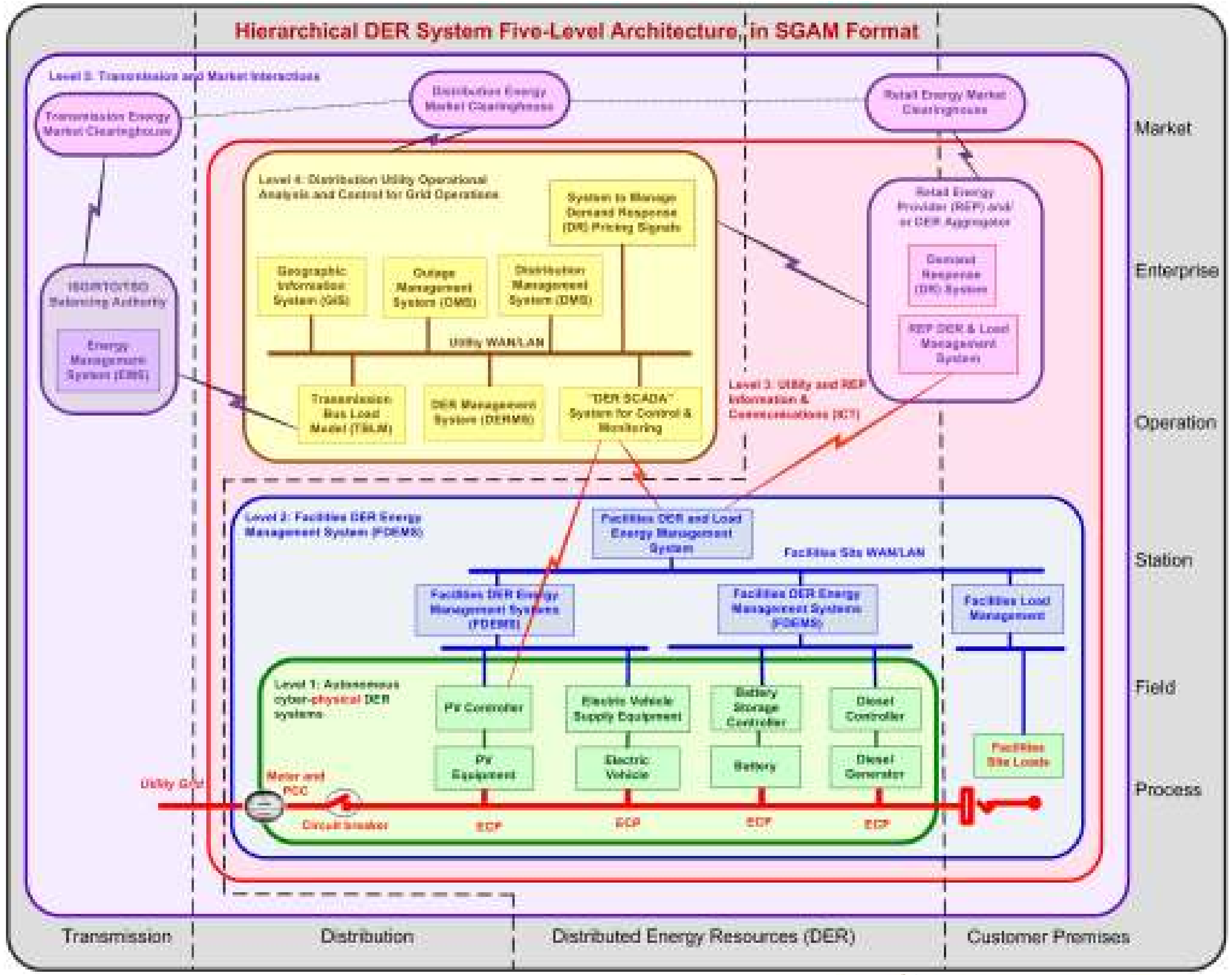


*Figure 1: 5-Level Hierarchical DER System Architecture (August 2013 draft)*

# Transmission impacts are evaluated using current CAISO studies evaluating DG integration

- Study excludes independent analysis of CA bulk supply system
- Study incorporate results from:
  - Most recent CAISO Transmission Resource Plan
  - Most recent CAISO Resource Adequacy Study
    - Available capacity is 892 MW at 57 delivery points over the entire SCE system
    - Availability varies by delivery point location
    - Represents potential constraint for DG capacity
    - CAISO Resource Adequacy limits applied to non-NEM DG
  - Related DG analyses and reports
- Subtransmission impacts (SCE) analyzed separately from distribution

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NAVIGANT ENERGY

# The feeder analysis includes parametric studies for the urban and rural DG scenarios

## Total DG by Region and by Feeder

| Rural / Urban DG | 70% Rural 30% Urban | 50% Rural 50% Urban | 30% Rural 70% Urban |
|---|---|---|---|
| Urban DG (MW) | 1440 | 2400 | 3360 |
| Rural DG (MW) | 3360 | 2400 | 1440 |
| Total DG (MW) | 4800 | 4800 | 4800 |

| | | | |
|---|---|---|---|
| DG/Feeder - Urban (MW) | 0.44 | 0.74 | 1.04 |
| DG/Feeder - Rural (MW) | 5.33 | 3.81 | 2.29 |

***Amount of DG allocated for each feeder based on feeder load, and urban versus rural split***



NAVIGANT ENERGY

# The feeder analysis for the 30 percent rural, 70 percent urban DG case results in few voltages and loadings violations

| Feeder | Urban / Rural | DG Capacity (MW) | Load (Max / Min) | Baseline Voltage (S/S) | S/S Voltage (w/ DG) | Baseline Voltage (EOL) | EOL Voltage (w/ DG) | Max Voltage Drop/Rise | Baseline Max Loading | Max Loading Net of DG | Max Change in Loading |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feeder 1 | Urban | 1.24 | Max | 124.6 | 124.8 | 123.8 | 125.1 | 1.3 | 39% | 32% | -7% |
| | | | Min | 124.6 | 125.0 | 123.8 | 125.6 | 1.8 | 23% | 30% | 7% |
| Feeder 2 | Urban | 0.90 | Max | 122.4 | 122.4 | 121.4 | 122.5 | 1.1 | 69% | 64% | -5% |
| | | | Min | 122.4 | 122.6 | 121.4 | 122.7 | 1.3 | 41% | 60% | 19% |
| Feeder 3 | Urban | 1.45 | Max | 124.2 | 124.3 | 119.1 | 121.6 | 2.5 | 80% | 71% | -9% |
| | | | Min | 124.2 | 124.7 | 119.1 | 123.7 | 4.6 | 48% | 37% | -11% |
| Feeder 4 | Urban | 1.72 | Max | 125.0 | 125.5 | 123.3 | 124.5 | 1.2 | 60% | 51% | -9% |
| | | | Min | 125.0 | 126.2 | 123.3 | 125.7 | 2.4 | 36% | 25% | -11% |
| Feeder 5 | Rural | 4.37 | Max | 125.1 | 125.3 | 121.9 | 123.9 | 2.0 | 71% | 38% | -33% |
| | | | Min | 125.1 | 125.7 | 121.9 | 125.7 | 3.8 | 43% | 29% | -14% |
| Feeder 6 | Rural | 1.06 | Max | 122.6 | 122.6 | 118.6 | 122.6 | 4.0 | 53% | 29% | -24% |
| | | | Min | 122.6 | 122.6 | 118.6 | 122.8 | 4.2 | 32% | 14% | -18% |
| Feeder 7 | Rural | 3.85 | Max | 124.6 | 124.7 | 123.0 | 130.5 | 7.5 | 72% | 70% | -2% |
| | | | Min | 124.6 | 124.8 | 123.0 | 132.5 | 9.5 | 43% | 80% | 37% |

Note: Negative voltage drop indicates a drop in voltage





NAVIGANT ENERGY

# The 50 percent rural, 50 percent urban DG case shows an increase in the number of violations of feeder voltages and loadings

| Feeder | Urban / Rural | DG Capacity (MW) | Load (Max / Min) | Baseline Voltage (S/S) | S/S Voltage (w/ DG) | Baseline Voltage (EOL) | EOL Voltage (w/ DG) | Max Voltage Drop/Rise | Baseline Max Loading | Max Loading Net of DG | Max Change in Loading |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feeder 1 | Urban | 0.88 | Max | 124.6 | 124.7 | 123.8 | 124.8 | 1.0 | 39% | 33% | -6% |
| | | | Min | 124.6 | 124.9 | 123.8 | 125.3 | 1.5 | 23% | 21% | -2% |
| Feeder 2 | Urban | 0.64 | Max | 122.4 | 122.4 | 121.4 | 122.5 | 1.1 | 69% | 64% | -5% |
| | | | Min | 122.4 | 122.6 | 121.4 | 122.6 | 1.2 | 41% | 60% | 19% |
| Feeder 3 | Urban | 1.04 | Max | 124.2 | 124.2 | 119.1 | 121.4 | 2.3 | 80% | 73% | -7% |
| | | | Min | 124.2 | 124.7 | 119.1 | 123.6 | 4.5 | 48% | 39% | -9% |
| Feeder 4 | Urban | 1.23 | Max | 125.0 | 125.3 | 123.3 | 124.3 | 1.0 | 60% | 54% | -6% |
| | | | Min | 125.0 | 126.1 | 123.3 | 125.5 | 2.2 | 36% | 28% | -8% |
| Feeder 5 | Rural | 7.28 | Max | 125.1 | 125.7 | 121.9 | 125.5 | 3.6 | 71% | 48% | -23% |
| | | | Min | 125.1 | 126.1 | 121.9 | 127.8 | 5.9 | 43% | 51% | 8% |
| Feeder 6 | Rural | 1.76 | Max | 122.6 | 122.6 | 118.6 | 122.6 | 4.0 | 53% | 25% | -28% |
| | | | Min | 122.6 | 122.6 | 118.6 | 124.1 | 5.5 | 32% | 26% | -6% |
| Feeder 7 | Rural | 6.41 | Max | 124.6 | 124.8 | 123.0 | >130 | >10 | 72% | 130% | 58% |
| | | | Min | 124.6 | 124.9 | 123.0 | >130 | >10 | 43% | 140% | 97% |

Note: Negative voltage drop indicates a drop in voltage



NAVIGANT ENERGY

# The 70 percent rural, 30 percent urban DG case shows an increase in the number and magnitude of feeder voltages and loading violations

| Feeder | Urban / Rural | DG Capacity (MW) | Load (Max / Min) | Baseline Voltage (S/S) | S/S Voltage (w/ DG) | Baseline Voltage (EOL) | EOL Voltage (w/ DG) | Max Voltage Drop/Rise | Baseline Loading (%) | Max Loading Net of DG | Max Change in Loading |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feeder 1 | Urban | 0.53 | Max | 124.6 | 124.7 | 123.8 | 124.7 | 0.9 | 39% | 35% | -4% |
| | | | Min | 124.6 | 124.9 | 123.8 | 124.9 | 1.1 | 23% | 30% | 7% |
| Feeder 2 | Urban | 0.39 | Max | 122.4 | 122.4 | 121.4 | 122.5 | 1.1 | 69% | 65% | -4% |
| | | | Min | 122.4 | 122.6 | 121.4 | 122.6 | 1.2 | 41% | 60% | 19% |
| Feeder 3 | Urban | 0.62 | Max | 124.2 | 124.2 | 119.1 | 121.2 | 2.1 | 80% | 75% | -5% |
| | | | Min | 124.2 | 124.6 | 119.1 | 123.4 | 4.3 | 48% | 42% | -6% |
| Feeder 4 | Urban | 0.74 | Max | 125.0 | 125.5 | 123.3 | 124.1 | 0.8 | 60% | 56% | -4% |
| | | | Min | 125.0 | 126.2 | 123.3 | 125.3 | 2.0 | 36% | 30% | -6% |
| Feeder 5 | Rural | 10.19 | Max | 125.1 | 126.1 | 121.9 | 127.5 | 5.6 | 71% | 70% | -1% |
| | | | Min | 125.1 | 126.5 | 121.9 | 129.8 | 7.9 | 43% | 72% | 29% |
| Feeder 6 | Rural | 2.47 | Max | 122.6 | 122.6 | 118.6 | 123.7 | 5.1 | 53% | 30% | -23% |
| | | | Min | 122.6 | 122.6 | 118.6 | 125.3 | 6.7 | 32% | 44% | 12% |
| Feeder 7 | Rural | 8.97 | Max | 124.6 | 124.7 | 123.0 | >130 | >10 | 72% | 187% | 115% |
| | | | Min | 124.6 | 124.8 | 123.0 | >130 | >10 | 43% | 196% | 153% |

Note: Negative voltage drop indicates a drop in voltage





NAVIGANT ENERGY

# When clustered at the end of the feeder, the magnitude and number of violations increases for the 30 percent rural, 70 percent urban DG case

| Feeder | Urban / Rural | DG Capacity (MW) | Load (Max / Min) | Baseline Voltage (S/S) | S/S Voltage (w/ DG) | Baseline Voltage (EOL) | EOL Voltage (w/ DG) | Max Voltage Drop/Rise | Baseline Max Loading | Max Loading Net of DG | Max Change in Loading |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feeder 1 | Urban | 1.24 | Max | 124.6 | 124.8 | 123.8 | 124.8 | 1.0 | 39% | 32% | -7% |
| | | | Min | 124.6 | 124.9 | 123.8 | 125.0 | 1.2 | 23% | 19% | -4% |
| Feeder 2 | Urban | 0.90 | Max | 122.4 | 122.4 | 121.4 | 122.5 | 1.1 | 69% | 64% | -5% |
| | | | Min | 122.4 | 122.6 | 121.4 | 122.9 | 1.5 | 41% | 60% | 19% |
| Feeder 3 | Urban | 1.45 | Max | 124.2 | 124.4 | 119.1 | 122.6 | 3.5 | 80% | 64% | -16% |
| | | | Min | 124.2 | 124.9 | 119.1 | 124.8 | 5.7 | 48% | 40% | -8% |
| Feeder 4 | Urban | 1.72 | Max | 125.0 | 125.5 | 123.3 | 124.6 | 1.3 | 60% | 53% | -7% |
| | | | Min | 125.0 | 126.2 | 123.3 | 126.1 | 2.8 | 36% | 53% | 17% |
| Feeder 5 | Rural | 4.37 | Max | 125.1 | 125.3 | 121.9 | 127.5 | 5.6 | 71% | 127% | 56% |
| | | | Min | 125.1 | 125.7 | 121.9 | 129.7 | 7.8 | 43% | 128% | 85% |
| Feeder 6 | Rural | 1.06 | Max | 122.6 | 122.6 | 118.6 | 122.8 | 4.2 | 53% | 39% | -14% |
| | | | Min | 122.6 | 122.6 | 118.6 | 124.5 | 5.9 | 32% | 41% | 9% |
| Feeder 7 | Rural | 3.85 | Max | 124.6 | 124.7 | 123.0 | >130 | >10 | 72% | 111% | 39% |
| | | | Min | 124.6 | 124.8 | 123.0 | >130 | >10 | 43% | 113% | 70% |

Note: Negative voltage drop indicates a drop in voltage





NAVIGANT ENERGY

# When clustered at the end of the feeder, the magnitude of violations increases significantly for the 70 percent rural, 30 percent urban DG case

| Feeder | Urban / Rural | DG Capacity (MW) | Load (Max / Min) | Baseline Voltage (S/S) | S/S Voltage (w/ DG) | Baseline Voltage (EOL) | EOL Voltage (w/ DG) | Max Voltage Drop/Rise | Baseline Loading (%) | Max Loading Net of DG | Max Change in Loading |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feeder 1 | Urban | 0.53 | Max | 124.6 | 124.7 | 123.8 | 124.7 | 0.9 | 39% | 35% | -4% |
| | | | Min | 124.6 | 124.9 | 123.8 | 124.9 | 1.1 | 23% | 19% | -4% |
| Feeder 2 | Urban | 0.39 | Max | 122.4 | 122.4 | 121.4 | 122.5 | 1.1 | 69% | 65% | -4% |
| | | | Min | 122.4 | 122.6 | 121.4 | 122.7 | 1.3 | 41% | 60% | 19% |
| Feeder 3 | Urban | 0.62 | Max | 124.2 | 124.3 | 119.1 | 122.1 | 3.0 | 80% | 73% | -7% |
| | | | Min | 124.2 | 124.8 | 119.1 | 124.2 | 5.1 | 48% | 47% | -1% |
| Feeder 4 | Urban | 0.74 | Max | 125.0 | 125.2 | 123.3 | 124.1 | 0.8 | 60% | 52% | -8% |
| | | | Min | 125.0 | 125.9 | 123.3 | 125.4 | 2.1 | 36% | 27% | -9% |
| Feeder 5 | Rural | 10.19 | Max | 125.1 | 126.0 | 121.9 | >130 | >10 | 71% | >200% | >100% |
| | | | Min | 125.1 | 126.3 | 121.9 | >130 | >10 | 43% | >200% | >100% |
| Feeder 6 | Rural | 2.47 | Max | 122.6 | 122.6 | 118.6 | 127.4 | 8.8 | 53% | 94% | 41% |
| | | | Min | 122.6 | 122.6 | 118.6 | 128.9 | 10.3 | 32% | 95% | 63% |
| Feeder 7 | Rural | 8.97 | Max | 124.6 | 124.8 | 123.0 | >130 | >10 | 72% | >200% | >100% |
| | | | Min | 124.6 | 124.9 | 123.0 | >130 | >10 | 43% | >200% | >100% |

Note: Negative voltage drop indicates a drop in voltage





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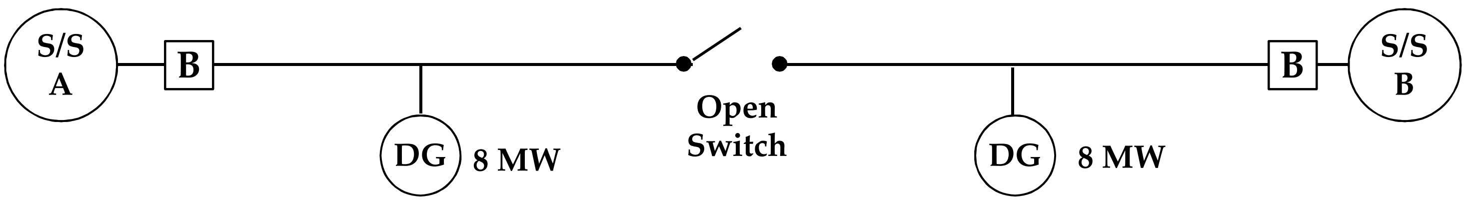
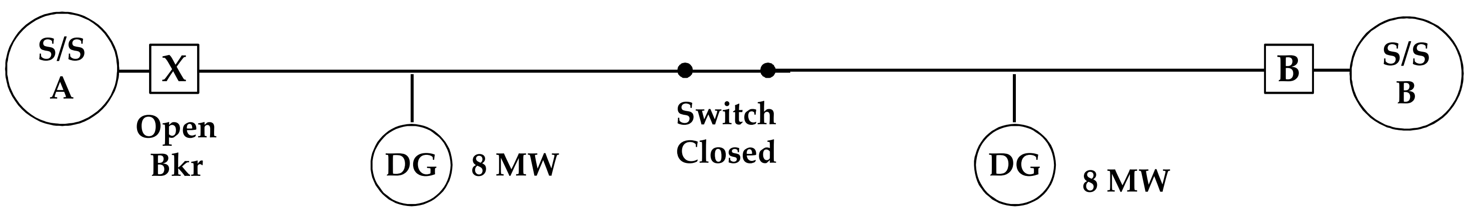
# Study results must conform to utility design standards and operating practices, which includes non-static feeder configuration

*The following illustrates how DG is impacted by standard operating practices:*

**(1) Normal conditions (feeder configuration) – Assume each feeder is able to interconnect 10 MW of DG**




**(2) After sectionalizing and transfer for maintenance or outage restoration (A to B)**




**Result: Total connected DG after transfer is 16 MW, which exceeds 10 MW limit by 6 MW**





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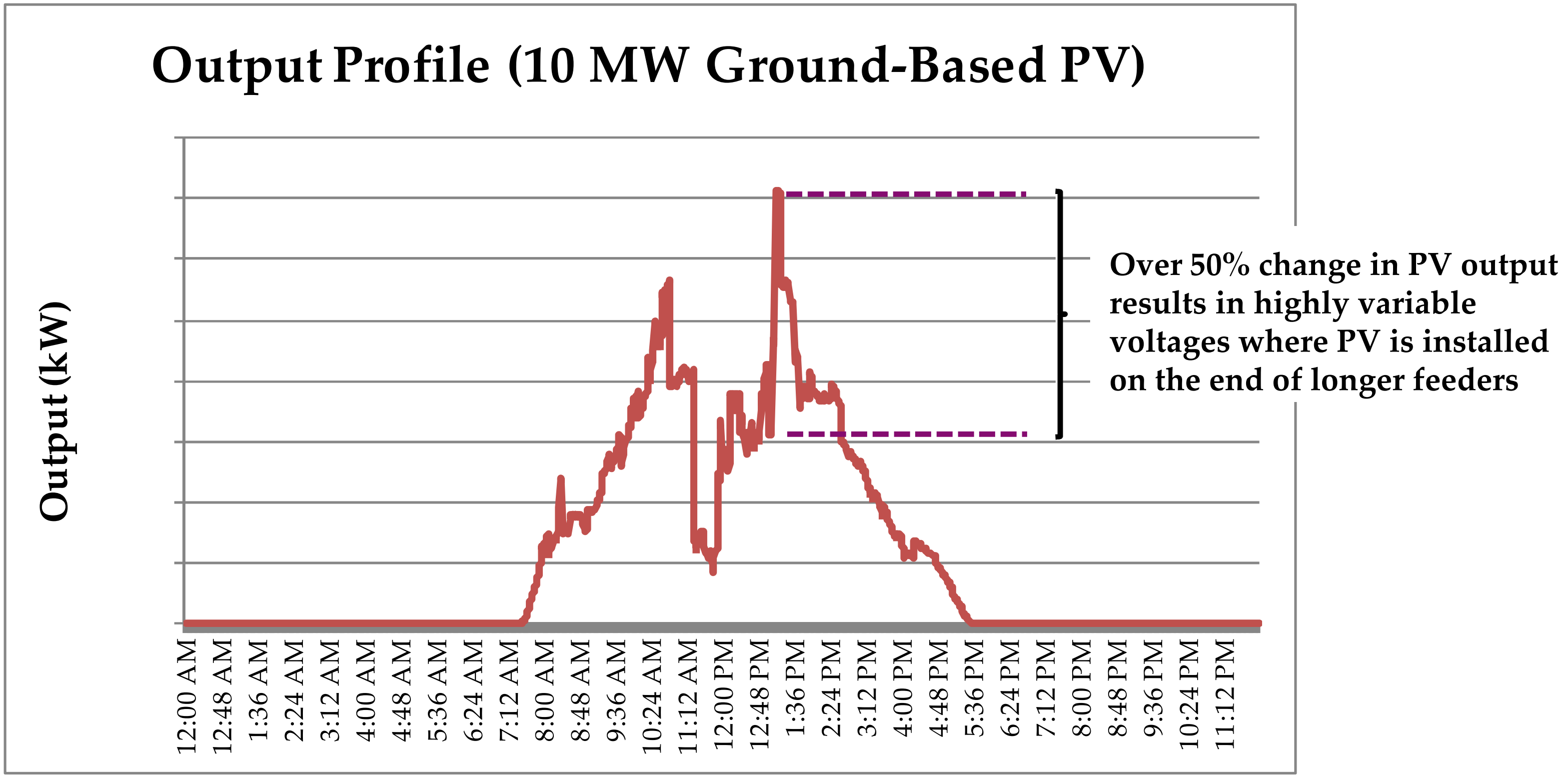
# Highly intermittent renewable output may create power quality violations on longer feeders

## Minute-by-minute PV changes in output produces significant voltage swings




*LTC's & voltage regulators typically do not respond quickly enough to stabilize voltage*

# The feeder analyses for SCE's distribution system produced a range of performance outcomes

## Key Results & Findings

1. Shorter feeders operating at 12kV or higher required few system upgrades, regardless of DG penetration
2. Longer rural feeders are subject to greater voltage variability, particularly for lightly loaded feeders
3. The impact of highly clustered DG is much more significant than DG that is equally distributed among feeders across the system
4. The impact DG integration in highly dependent on its location on a feeder. DG located at the end of the feeder require more extensive upgrades
5. New systems, processes and activities may need to undertaken to achieve the DG targets addressed in our study. These include:
   - Advanced communications and automated controls
   - Changes in design standards and criterion
   - Changes in operating practices and maintenance
   - Institutional and regulatory framework (e.g., utility control of customer DG)





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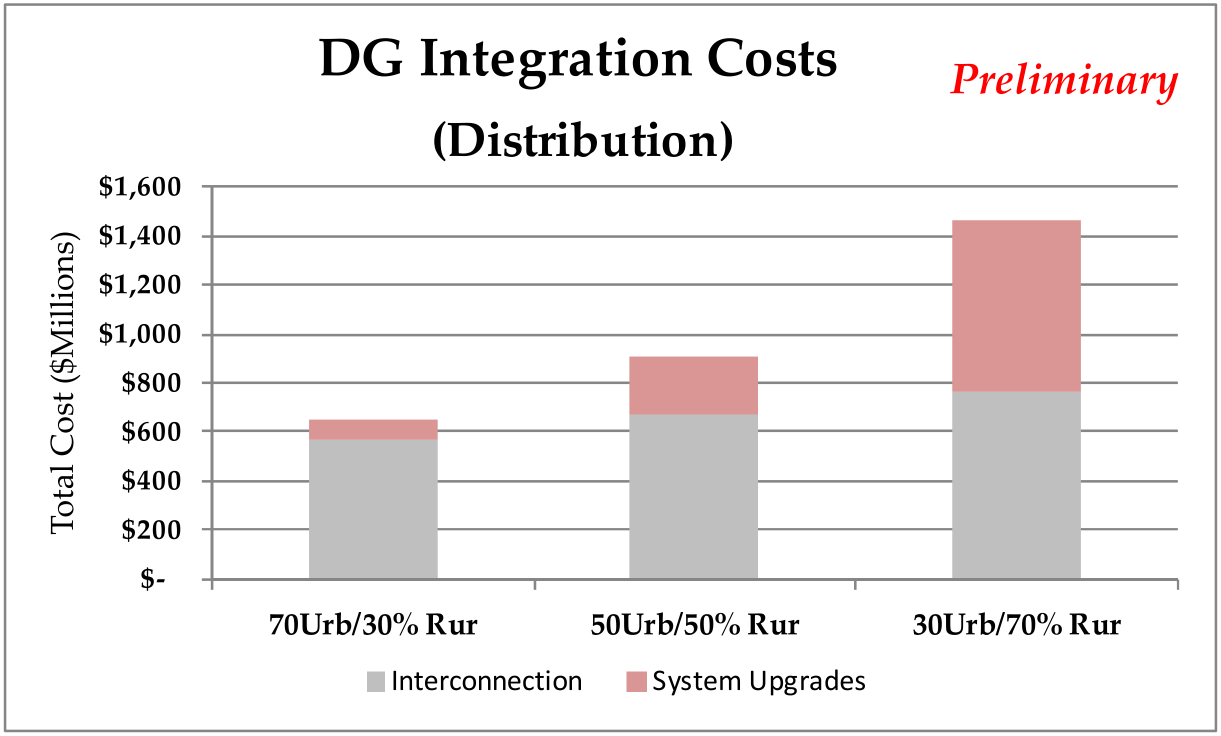
# Estimated DG integration cost ranges from a low of $600 million to a high of about $1.4 billion, with higher costs for greater amounts of rural DG

## DG Distributed Uniformly on Feeders




DG integration costs range from $130/kW to $300/kW for the distribution system

**Most costs are for upgrading rural feeders and the installation of voltage regulating devices**





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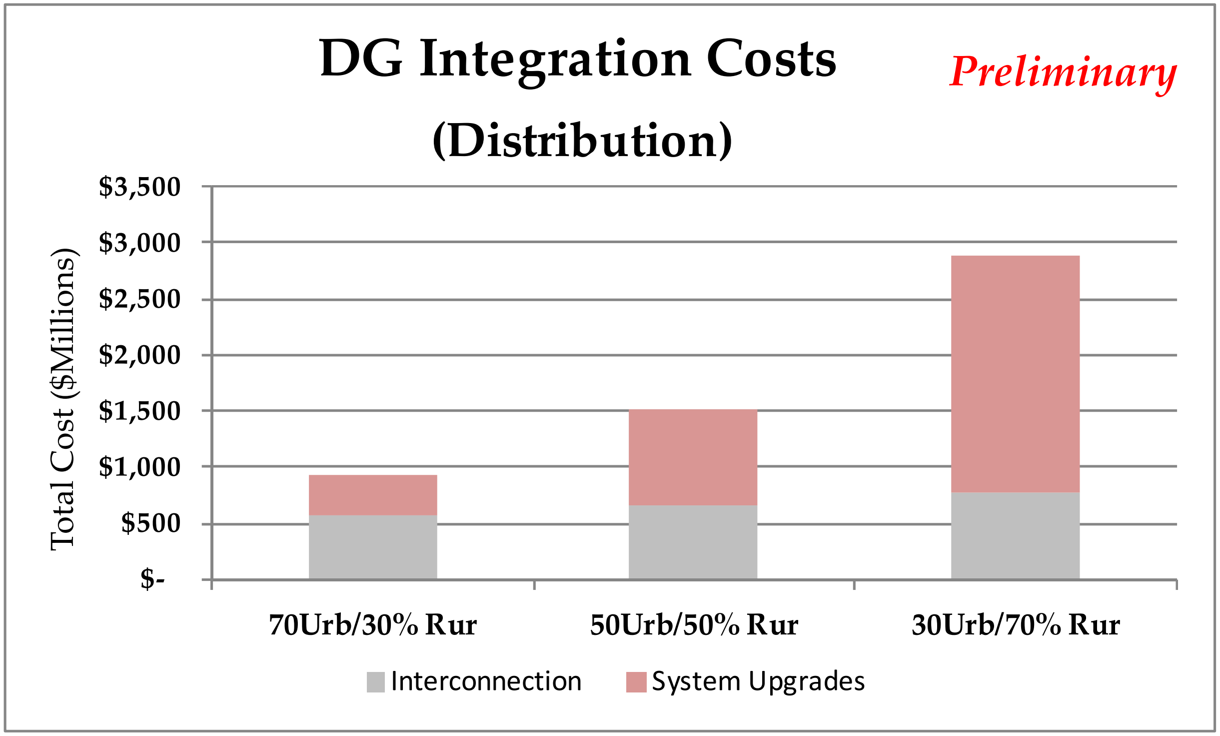
# The costs of integrating DG increases significantly if clustered in large quantities, particularly when located near the end of longer feeders

## Clustered DG




DG integration costs range from $200/kW to $600/kW for the distribution system

**Most costs are for upgrading and installing new rural feeders, upgrading urban feeders, and installing voltage regulating devices**

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# The cost to mitigate DG impacts in areas where transmission is constrained can be high, possibly exceeding distribution

SCE's May 2012 study illustrates how DG location can significantly increase (or decrease) integration costs

- Integration costs for the Unguided case (70% DG in rural areas) far exceeded the Guided case (70% DG in urban areas: $3.2 versus $1.0 billion for Unguided versus Guided case, respectively
- Transmission in urban areas (LA Basin) characterized by a highly networked, tight gird with few interface constraints (e.g., absence of congestion)
- Costs based on CAISO Cluster 4, Phase I study results ($/MW per zone to relieve transmission constraints or for reliability)

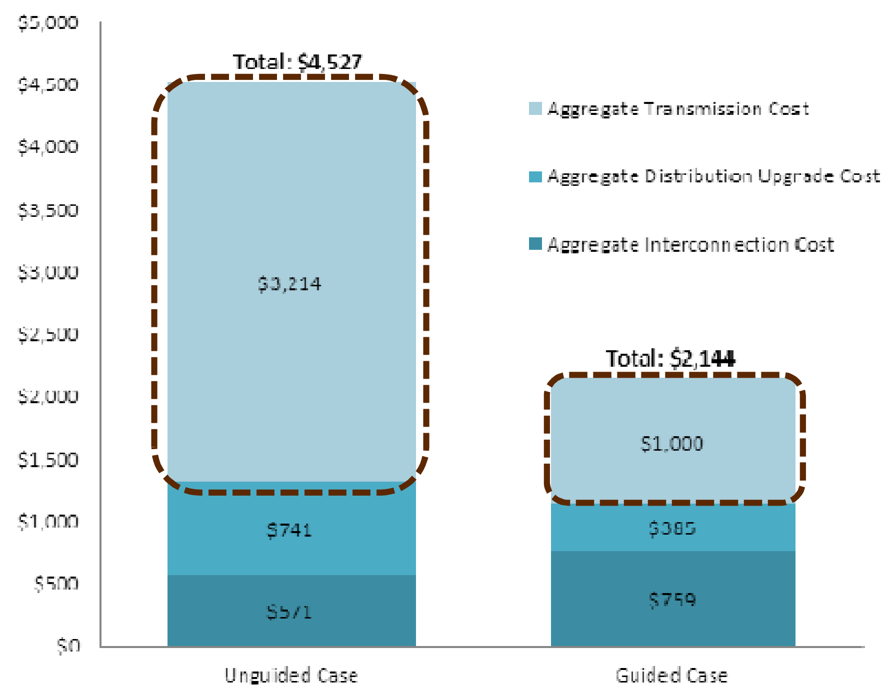

Figure 8. Total SCE system costs of LER Proposal

**Navigant is applying a similar approach based CAISO updates outlined in its Phase II, Queue 4 study. Results will be presented in the draft report**

# The DG integration study produced a range of outcomes and integration costs

**Key Takeaways:**

1. Cost of DG integration is highly dependent on where DG is installed. Integration impacts and costs are lower for DG installed in urban areas
2. DG integration costs vary as a function of key parameters and assumptions, including DG location on feeders and total installed capacity
3. DG integration costs increase significantly as greater amounts of DG is installed near the end of distribution lines
4. High penetration DG may require sophisticated communications and control systems to better manage DG impacts and reduce integration costs
5. Policies that "guide" or encourage DG in areas with fewer impacts would help achieve state renewables goals at lower cost

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NAVIGANT ENERGY

# Navigant will issue a draft report by early September that will include updated case studies and findings

| Action Item | Date |
|---|---|
| Issue draft report to CEC for review | Early Sept, 2013 |
| Draft report posted for public comment | Mid to late Sept, 2013 |
| Deadline for comments | Mid Oct, 2013 |
| Final report issued to CEC | End of Oct, 2013 |
| Final report posted | Mid Nov, 2013 |



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NAVIGANT ENERGY

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# The process includes review and input from a Project Advisory Committee (PAC) comprised of electric utility representatives.

## Specific question raised before the PAC included:

1. Is the feeder selection method appropriate to represent a utility's feeder population? If not, are there other methods that CEC should consider?
2. Is the feeder model (based on the example shown) appropriate to capture the complexity of a feeder? If not, what would be more appropriate?
3. Is the operational impact analysis appropriate? If not, are there other operational impacts that CEC should consider in this framework?
4. Is the method to analyze DG potential per feeder appropriate? If not, what methods should CEC consider?
5. Are the case studies described appropriate to understand the range of DG potential? If not, what additional case studies should CEC consider?
6. Are there certain characteristics of your system or DG programs that require additional assumptions, models or solutions?

# Feeder selection (13 classifications for ~4,500 SCE feeders) is based on weighting selected feeder metrics in a clustering algorithm

» 9 feeder metrics were used to drive a clustering algorithm:

| | |
|---|---|
| – Urban/rural classification | 4X weight |
| – Nominal voltage (~4 kV, 12-16 kV, ~33 kV) | 4X weight |
| – Total 3-ph ckt miles | 3X weight |
| – Total 2-ph and 1-ph ckt miles | 3X weight |
| – Feeder peak loads, Amps | 3X weight |
| – Residential (%) | |
| – Commercial (%) | |
| – Commercial customers | |
| – Domestic customers | |





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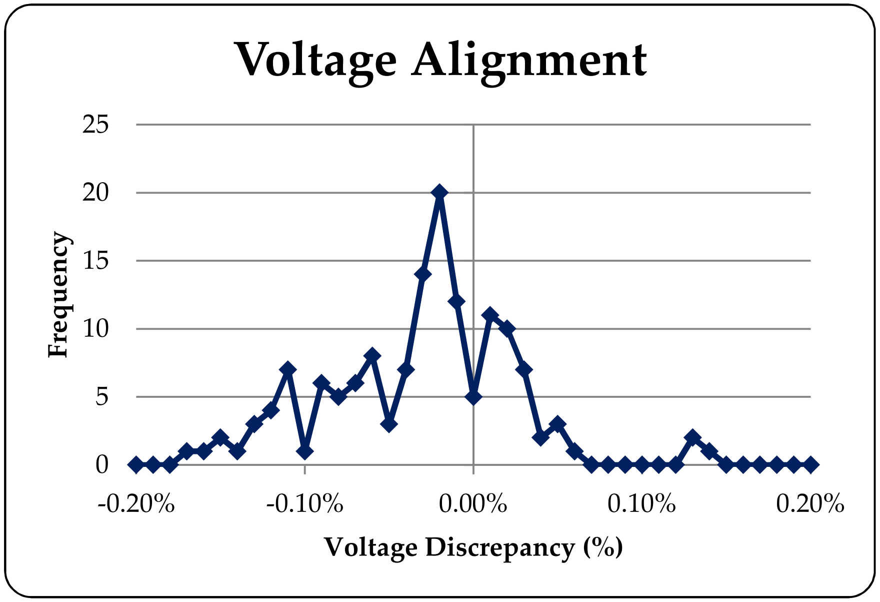
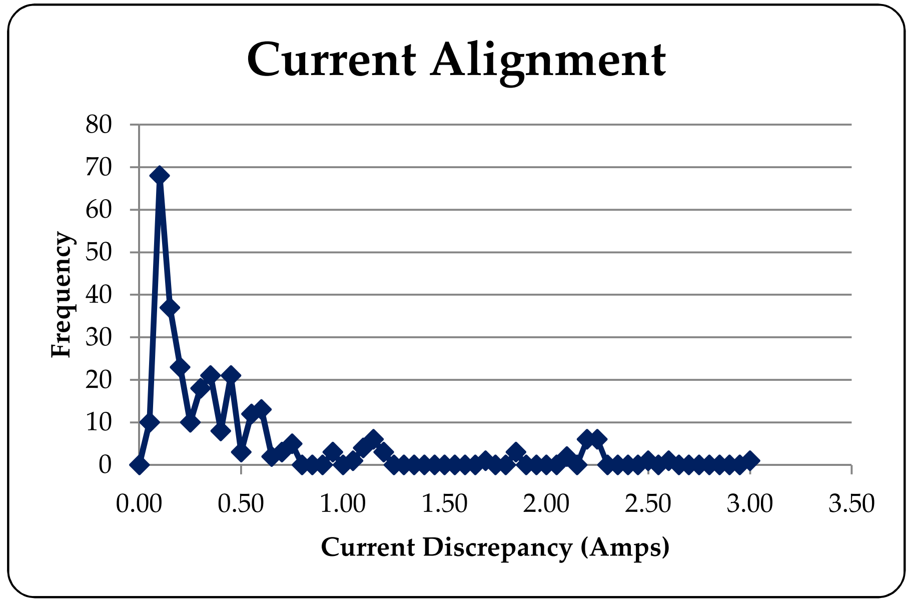
# Import and conversion of SCE model database to Milsoft reconciled closely with SCE CYME model results (used in SCE's May 2012 study)

- Conducted spot checks of Urban 12 kV feeder voltage and current node-to-node, to ensure calibration between SCE model and Navigant's model.
- Very close similarity between values for baseline case (no DG). Histograms shown below.
  - Voltage differs on average by less than 0.05%
  - Current differs on average by less than 0.5 A
- Simulations of DG integration can be trusted to accurately reflect changes to system.




***All base case models verified with SCE prior to DG integration analysis***

# SCE-Navigant CYME – Milsoft conversation flowchart illustrates model verification process