Panel: Solar PV on Distribution Circuits

Determination of Mitigation Solutions

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Importance of PV Impact Studies

- Model-based studies are used to inform the cost of PV interconnection
  - Majority of PV is installed on distribution[1]
  - Outcome of studies (i.e. $$ needed to interconnect) makes or breaks many PV projects
  - Scope of the studies heavily influences the mitigation cost if allowable impact is surpassed

PV impact studies are intrinsically intertwined to mitigation studies

[1]Palmintier et al., "Emerging Issues and Challenges in Integrating Solar with the Distribution System." NREL Tech. Report TP-5D00-65331, May, 2016.

NREL/SCE Hi-Pen PV Project

5 MW Fixed-Tilt Ground-Mount System near Porterville, CA

2 MW Warehouse Roof Mounted PV System near Fontana, CA

- Impetus – SCE installing 500 MW of distribution-connected utility scale solar
- Focus – impact and mitigation of 1-5 MW PV systems
- Goal – easing the interconnection concerns of utilities faced with utility-scale distribution-connected PV systems

Using salient points in time…

- When determining PV mitigation measures how can we approach the model-based PV mitigation analysis to get a reliable output with minimal input?
- 1 year of quasi-static time-series analysis
  - 30M to 500k static solutions – 60hrs to 1hr
- Can we look at a few salient points in time (or important days) and get 80% of the value?

PV Impact/Mit. Study Approach

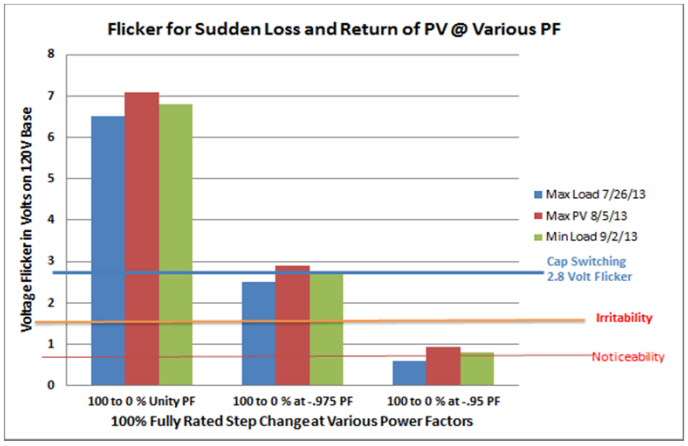
- Impacts assessed:
  - Voltage step change
  - Controller movement
  - Fault/protection
- Additional analysis:
  - Variability analysis
  - Impact mitigation options/settings
- Salient time points:
  - Maximum load time point
  - Minimum load time point
  - Maximum PV generation time point
  - Maximum ratio of PV generation to load
  - Maximum difference between PV generation and load

See: B. Mather, et. al "NREL/SCE High-Penetration PV Integration Project: Annual Report FY 13," NREL Technical Report TP-5D00-61269, 2014.

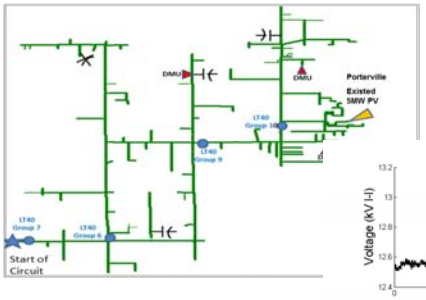
Voltage Step Change Analysis Approach

- For each salient operating point:
  - Model PV at 100% rated, solve
  - Lock controlled elements and reduce PV to 0% (100% loss), solve
  - Measure voltage step change, unlock controlled elements, solve
  - Lock controlled elements and increase PV to 100% rated, solve
  - Measure voltage step again (100% return)

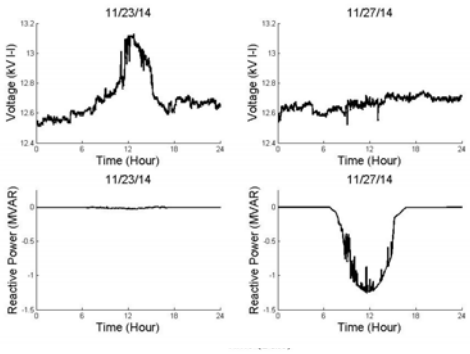
A Look at Mitigation Techniques/Settings



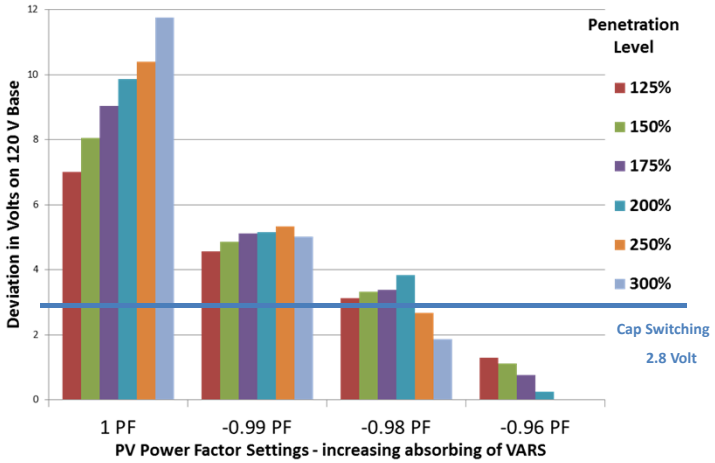
Taking Study Results to the Field



PCC voltage impact mitigation was 3% p.u. – matching expectations

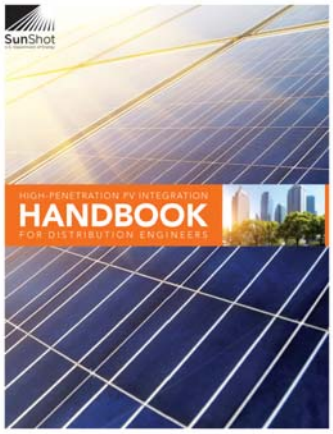


Mitigation Studies at Higher Pen



See: D. Cheng et al. "Photovoltaic (PV) Impact Assessment for Very High Penetration Levels," IEEE Jour.of PV, pp. 295-300, Jan. 2016,

High-Pen PV Integration Handbook



Developed under the auspices of the NREL/SCE Hi-Pen PV Integration Project Specifically for Distribution Engineers

Chapter 4 focuses on mitigation options

Available at:

http://www.nrel.gov/docs/fy16osti/63114.pdf

Thank you for your attention.

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The Impacts of DERs on Long-Term System Planning

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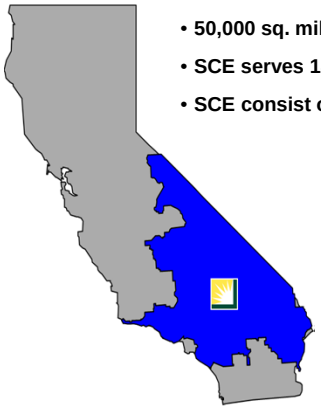
Presentation Objective and SCE Introduction

Discuss the impacts of DERs on System Planning and Grid Operations and SCE's plan to leverage technology to address it



- **50,000 sq. miles**
- **SCE serves 14 million customers and 5 million meters**
- **SCE consist of 4 operational zones**

- **900 Substations**
- **5,000 Transmission/Distribution circuits**
- **110,000 Circuit Miles**
- **1.6 million Transmission/Distribution poles**
- **720,000 Substation/Transmission/Distribution Transformers**
- **700,000 Street Lights**

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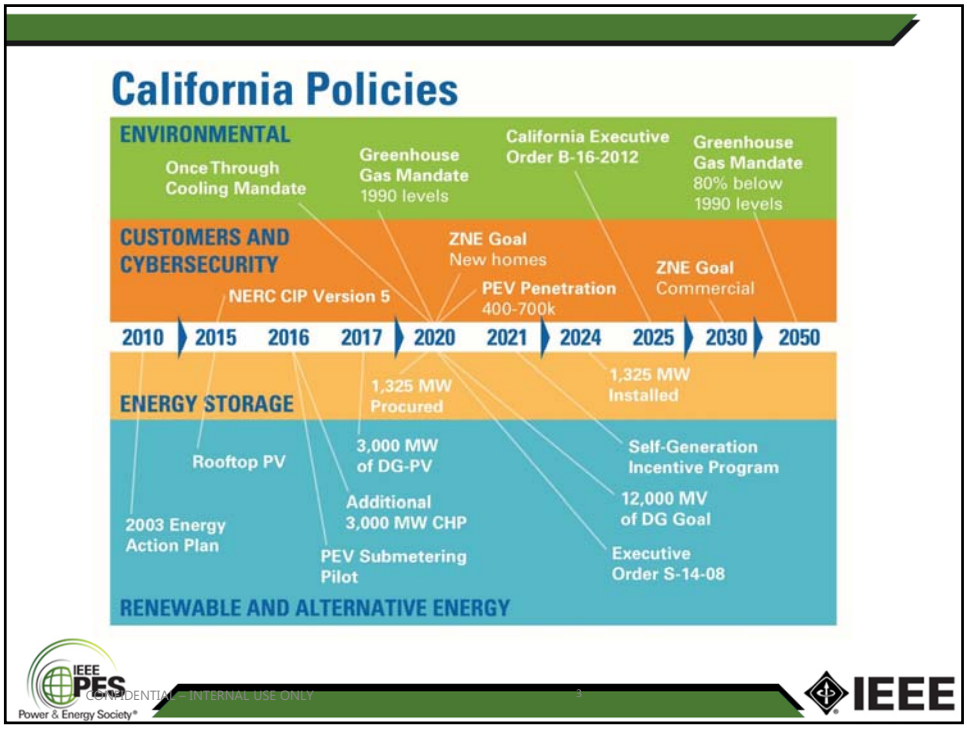
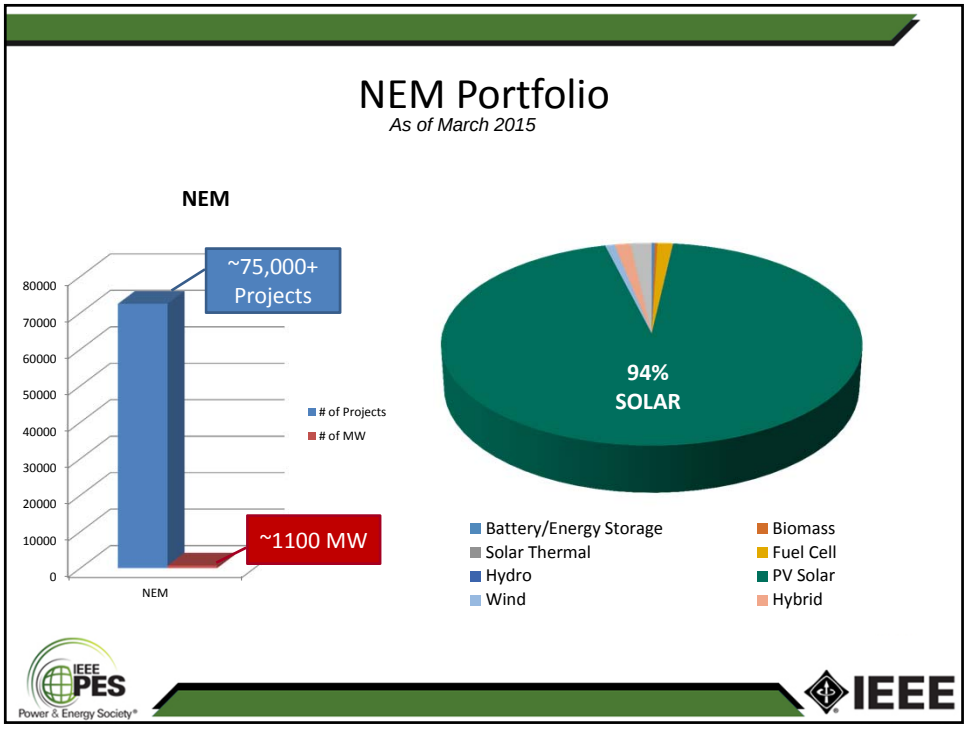


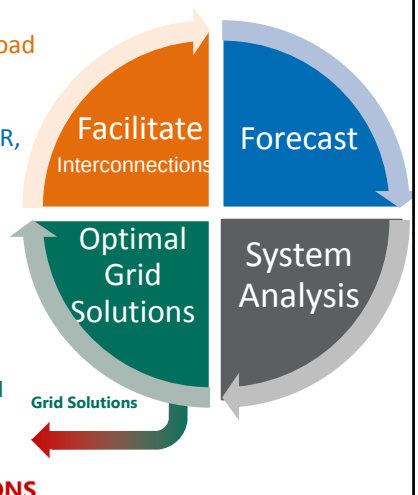


DER Integration is Significantly Impacting SCE's Long-Term System Planning

- Impact of DERs on Long-Term System Planning
  - Interconnection Process
  - Forecasting
  - System Analysis
  - Optimal Grid Solutions
- DERs are driving Integrated Planning and Operations
- Overview of SCE's Grid Modernization Software Roadmap
- Summary

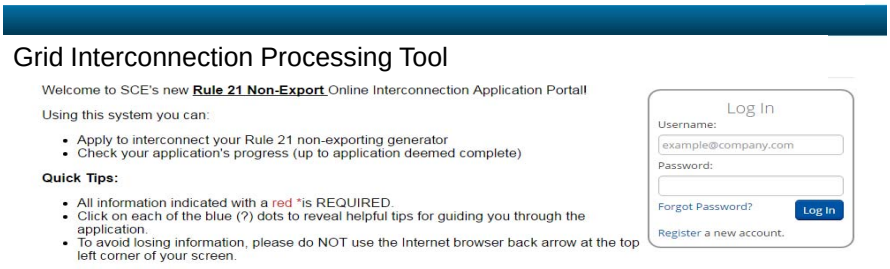
System Planning Objectives

1. Analyze and incorporate customer initiated load and generation ***Interconnections***
2. Perform a consistent and integrated load, DER, and generation ***Forecast***
3. Perform a risk-based, integrated ***System Analysis*** across organizations
4. Develop ***Optimal Grid Solutions*** (including evaluating utilizing DERs and traditional infrastructure projects)



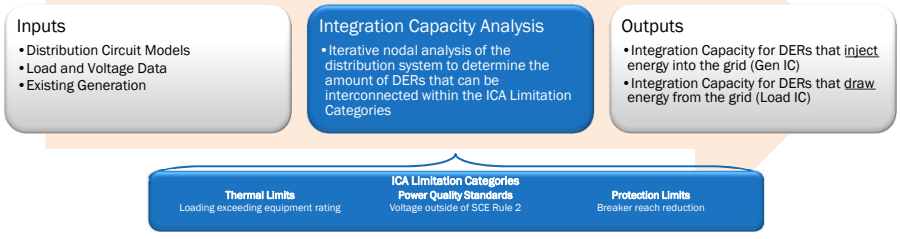
Customer facing tools are required to facilitate the Interconnection Process

- **Streamlined Interconnection**
  - Software tools are required to facilitate the interconnection process
- **Technical Analysis**
  - Streamlined technical analysis using power system modeling tools
  - Integration Capacity Analysis
- **Enhanced Customer Experience**
  - Provide information and status to SCE Customers regarding potential and current interconnection Requests



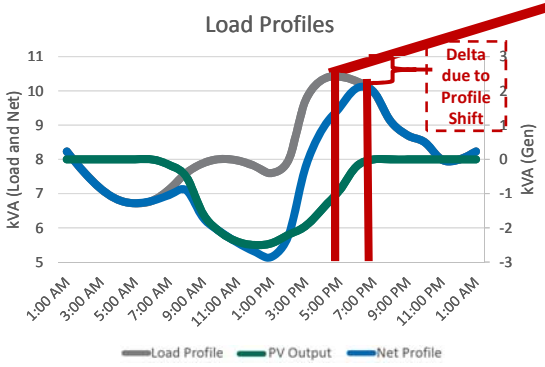
Integration Capacity Analysis (ICA) allows customers to identify low impact areas to interconnect

- The ICA quantifies the amount of DERs that can be interconnected on each node[1] across the distribution system within thermal, voltage, and protection system limits
  - ICA answers the question, "How much generation can I install on this line section without triggering distribution system upgrades?"
- SCE used the Interconnection Study Process as the foundation of its ICA Methodology development
  - ICA can streamline the DER interconnection process by simplifying the ISP, supplemental review, and elimination of some Fast Track limits



[1] Node is the transition point between electrical devices, as modeled by SCE mappers. Distribution circuits can have upwards of a thousand nodes

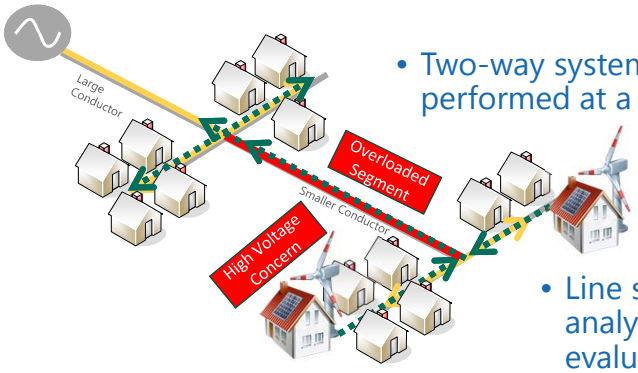
Long-Term Forecasting Must Incorporate The Impacts of DERs on Load Profiles



- Point-based peak forecasting
  - Used historically
  - Assumes no significant profile changes
- Daily profiles are changing due to DERs
  - Accounting for profile changes is challenging using point forecasts
- Profile-based forecasting
  - Required to account for profile changes

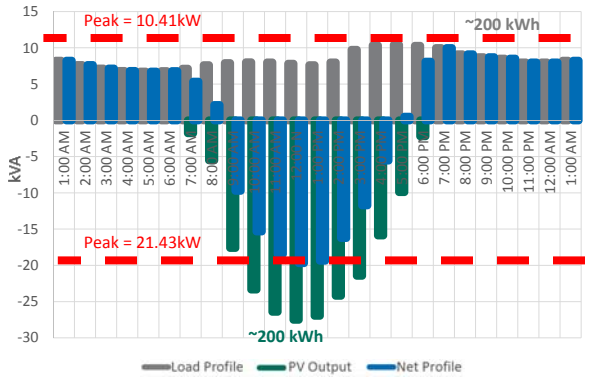
System Analysis is Becoming Complex due to DERs

- One-way system analysis was performed at a feeder level



- Two-way system analysis must be performed at a more granular level
- Line segment and voltage analysis is crucial to evaluate DER impacts

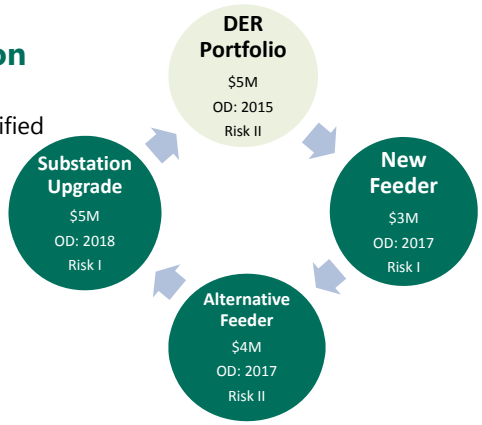
DERs Sized to Offset Energy Can Create Overloads

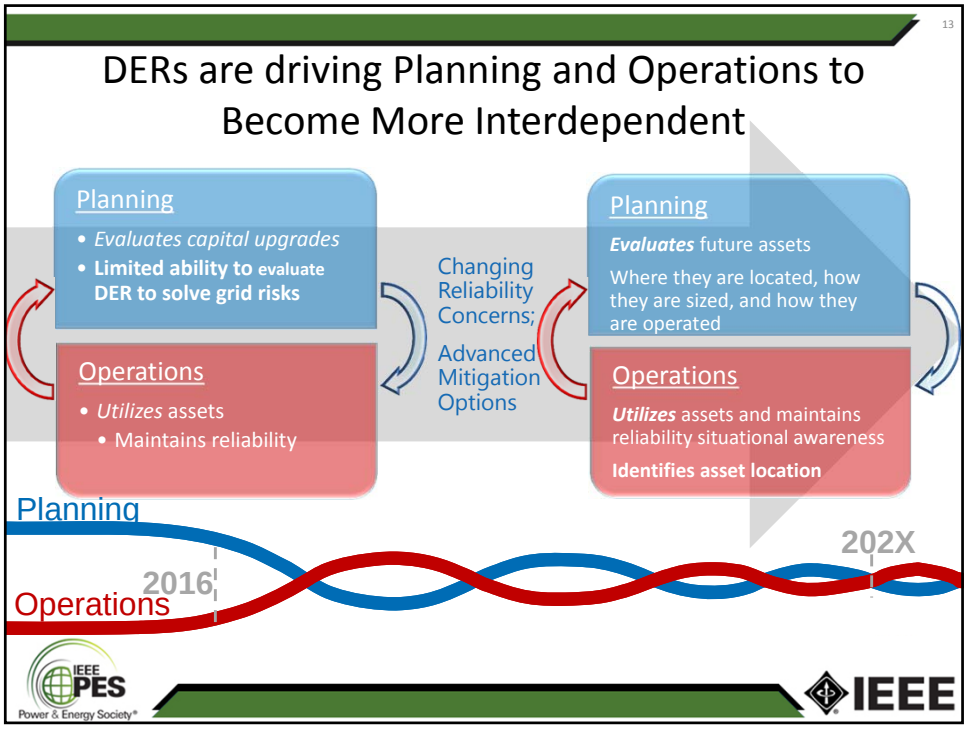


- Energy is consumed 24 hours a day
- Solar can only generate during daylight hours
- Solar must be oversized to account for non daylight hours
- May result in significantly higher generation loading during daylight hours

Grid Solution Portfolios Must be Optimized in order to Fully Leverage DERs

- **Risk mitigation options are changing to include relying on DER**
  - Multiple mitigations should be identified for each project
  - Mitigations must be evaluated to determine the optimal grid solution
- **Mitigation evaluation must include Net Benefits**
  - Costs must be evaluated
  - Risk reduction must be determined
  - Execution risks must be identified
  - Net-Benefits must be calculated

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DERs are driving Planning and Operations to Become More Interdependent
Planning
• Evaluates capital upgrades
• Limited ability to evaluate DER to solve grid risks
Operations
• Utilizes assets
• Maintains reliability
Changing Reliability Concerns;
Advanced Mitigation Options
Planning
Evaluates future assets
Where they are located, how they are sized, and how they are operated
Operations
Utilizes assets and maintains reliability situational awareness
Identifies asset location
Planning
Operations
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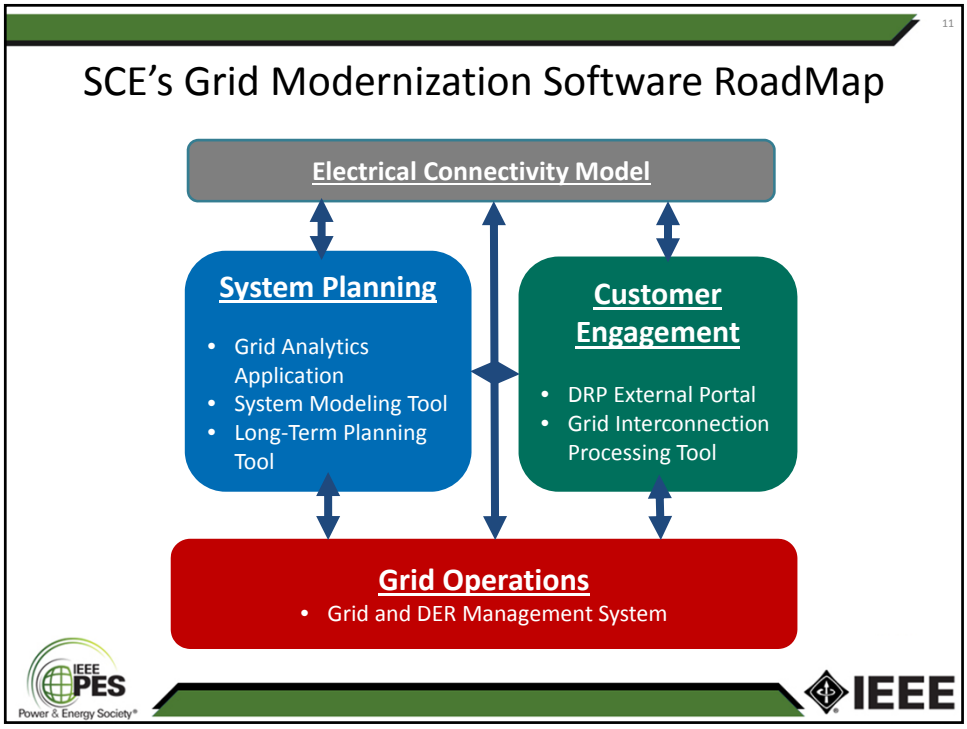
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SCE's Grid Modernization Software RoadMap
Electrical Connectivity Model
System Planning
• Grid Analytics Application
• System Modeling Tool
• Long-Term Planning Tool
Customer Engagement
• DRP External Portal
• Grid Interconnection Processing Tool
Grid Operations
• Grid and DER Management System
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Summary

1. Integration of DERs changes the way SCE plans and operates the electric grid
2. New types of analysis and evaluation are required
3. Long-Term System Planning and Grid Operations are becoming more dependent

Questions?

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Method for Calculating and Increasing Hosting Capacity for PV on Distribution Systems

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IEEE Innovative Smart Grid Technologies (ISGT) Conference, Minneapolis, MN, September 2016

What is Hosting Capacity and Why is it So Important?

- Definition:
  - Hosting Capacity is the amount of DER that can be accommodated without adversely impacting power quality or reliability under current configurations and without requiring infrastructure upgrades.
- Hosting Capacity is
  - Location dependent
  - Feeder-specific
  - Time-varying

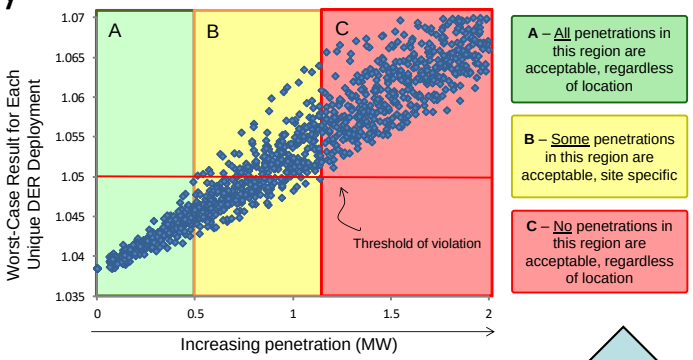
Hosting Capacity can be used to inform utility interconnection processes and to support DG developer understanding of more favorable locations for interconnection

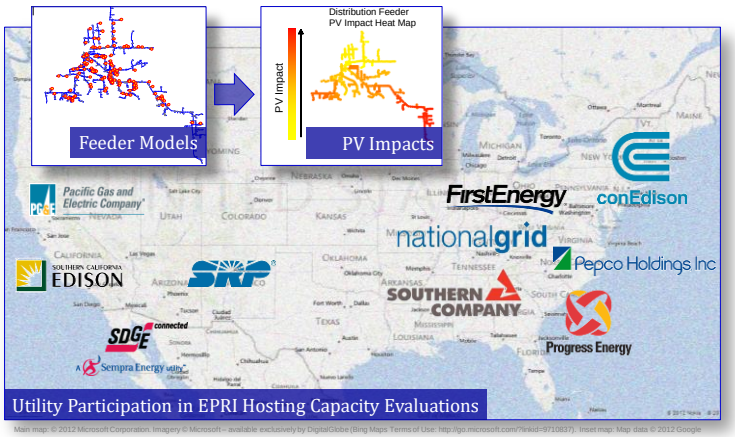
- Hosting capacity considers DER interconnection without allowing
  - Voltage/flicker violations,
  - Protection mis-operation
  - Thermal overloads
  - Decreased safety/reliability/power quality

Evolution of Hosting Capacity Methodology

Evolution of Hosting Capacity Methods

- Detailed hosting capacity methods first used to quantify
  - How much DER can be accommodated
  - Where can DER be accommodated
  - What distribution impacts occur
- Industry-wide application
  - Over 6 million unique DER deployment scenarios evaluated across >30 feeders and > 12 utilities
- Lessons learned
  - Location matters
  - No two feeders are alike – feeder clustering not sufficient
  - Rules-of-thumb aren't effective (DER as % of load for example)
  - Detailed analysis not easily replicable across large number of feeders
- New methods can be developed based learnings to "streamline" the analysis

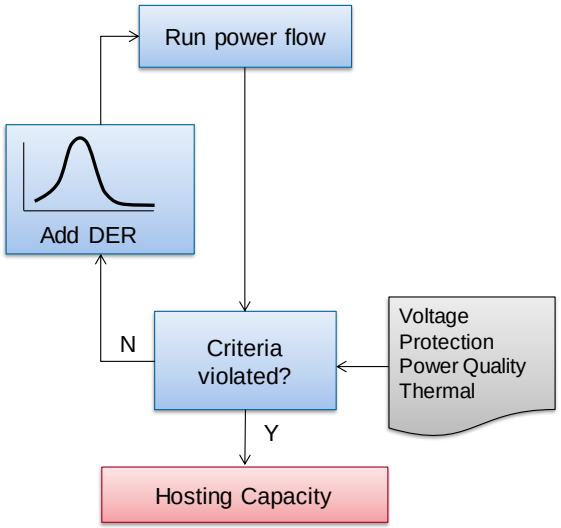




Detailed Implementation of Hosting Capacity Assessments

Method Overview

- Select specific locations for DER
- "Iterate" through each case
- Solve 1000's of load flows

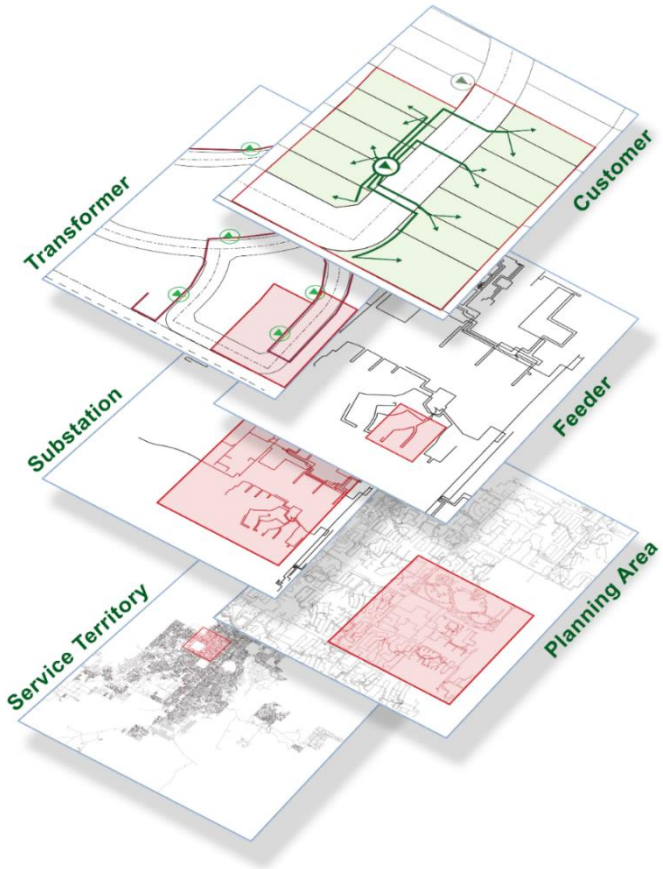


Findings

- Results similar to detailed impact studies
  - Accurate
  - Time-consuming/data intensive
  - Applicable to specific scenarios
- Difficult to consider range of possible DER scenarios
  - All locations (three-phase and single-phase)
  - Feeder reconfigurations
  - DER types
- Not easily replicable across entire system
  - Typically have to limit the cases/locations/scenarios considered
  - Can take hours to days to simulate a single feeder depending upon feeder complexity

Analysis of High-Penetration Solar PV Impacts for Distribution Planning: Stochastic and Time-Series Methods for Determining Feeder Hosting Capacity. EPRI, Palo Alto, CA: 2012. 1026640

Large "Scale" of Distribution System Creates Challenges for Distribution Planners



- Typical utility responsible for 100's to 1000's of distribution feeders
- Each feeder uniquely designed and operated to reliably serve all customers
- Methods needed that can be applied across entire distribution service territory

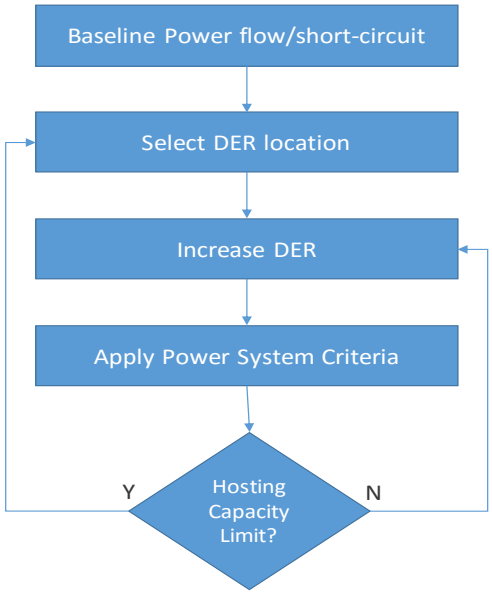
EPRI's Streamlined Hosting Capacity Method

Granular	• Capture unique feeder-specific responses
Repeatable	• As distribution feeders change
Scalable	• System-wide assessment
Transparent	• Clear and open methods for analysis
Proven	• Validated techniques
Available	• Utilize readily available utility data and tools

Streamlined Implementation of Hosting Capacity Assessments

Method Overview

- Solve base load flow/short-circuit cases
- Increase DER at each location on feeder
- Apply advanced algorithms to calculate hosting capacity at each location



Findings

- Close approximation of DER impact
  - Less time/data intensive
  - Not a replacement for detailed studies
- Full range of possible DER scenarios can be considered
  - All locations (three-phase and single-phase), feeder configurations, DER technologies and types (centralized vs distributed)
- Easily replicable across entire system
  - Typically 3-5 minutes per feeder when automated

Integration of Hosting Capacity Analysis into Distribution Planning Tools. EPRI, Palo Alto, CA: 2016. 3002005793

Streamlined Hosting Capacity Method – What is it?

2010 | 2011 | 2014 | 2015 | 2016/17

Develop original method → Utility application → **Streamlining method development** → Streamlined method application → Vendor implementation

The Input

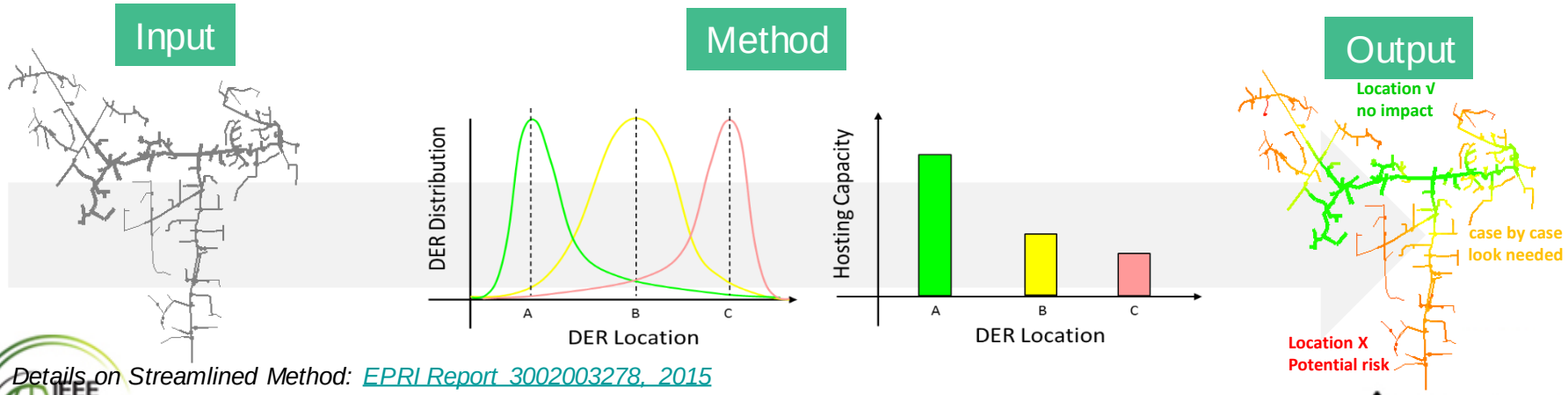
- Utilizes existing planning tools
  - CYME, Milsoft, Synergi

The Method

- Developed from years of detailed hosting capacity analysis
- Validated and open methods

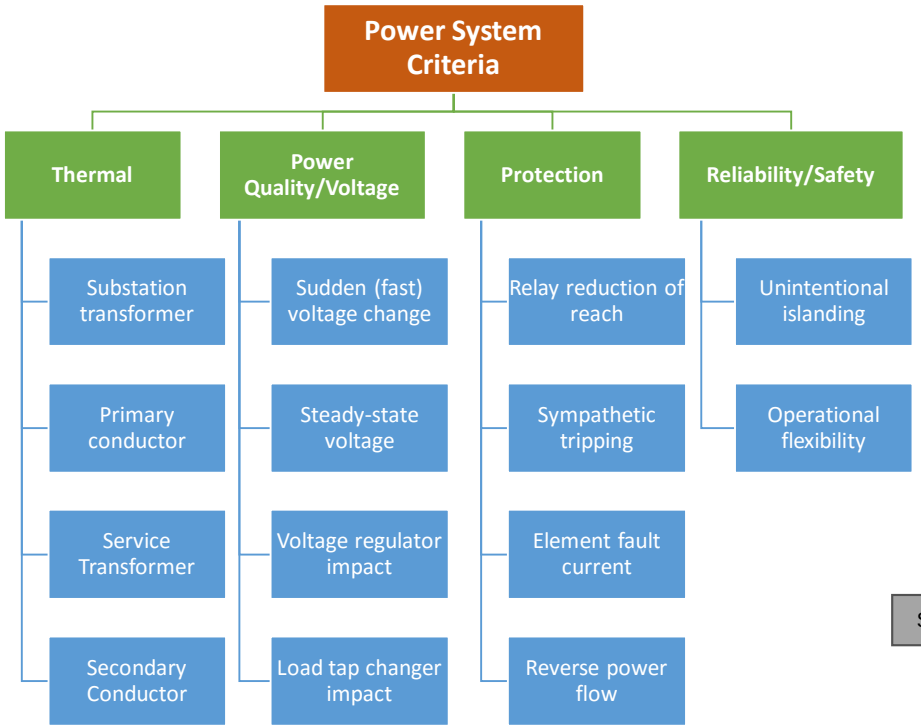
The Output

- Effectively and efficiently analyzes each and every feeder in system
- Considers DER size and location
  - Small distributed and large centralized DER
- Considers DER technology and impacts
  - PV, wind, storage, etc
  - Voltage, thermal, protection

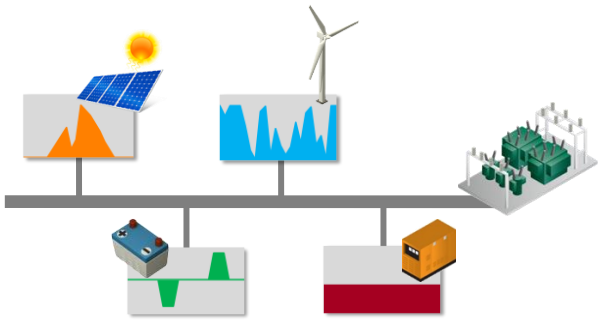


Details on Streamlined Method: [EPRI Report 3002003278, 2015]

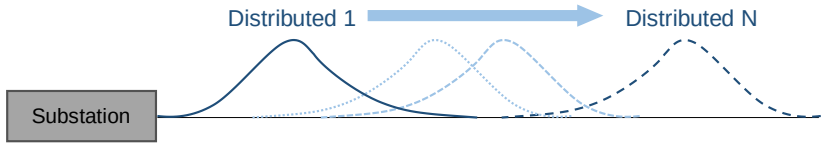
Key Aspects of Hosting Capacity Method
Power System Criteria and DER

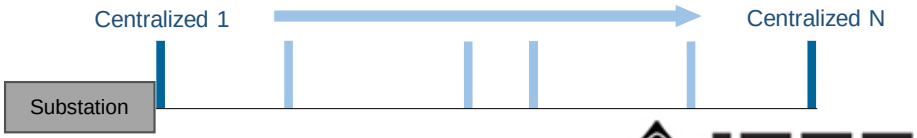


Unique DER Technology



DER Size and Location
Distributed and Centralized





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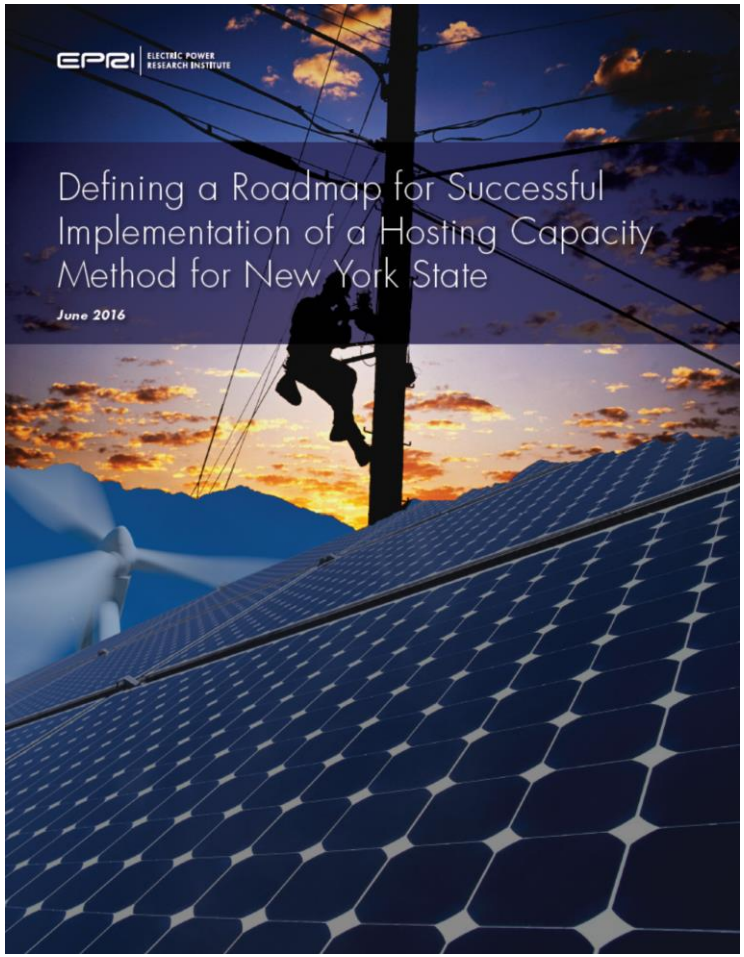
Utility Applications

- Informing developers
- Assisting with screening
- Planning for DER
- Identifying cost-effective means for increasing hosting capacity



Defining a Roadmap for Successful Implementation of a Hosting Capacity Method for New York State, EPRI, Palo Alto, CA: 2016. 3002008848

Utility applications to date

- TVA, Southern Company, Salt River Project, XCEL Energy, SCE, Central Hudson, National Grid, HydroOne, Austin Energy, CFE (Mexico), ESKOM (S. Africa), ESB (Ireland)

Sample Results

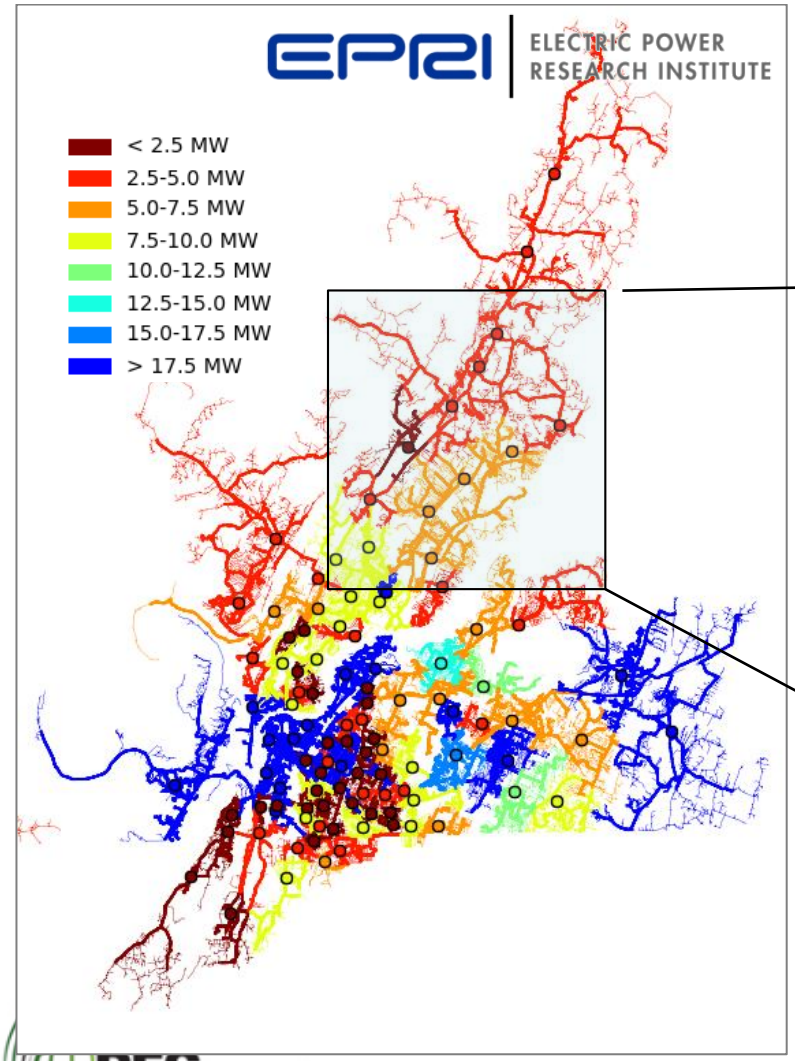
○ Substation Marker

*Hosting Capacity

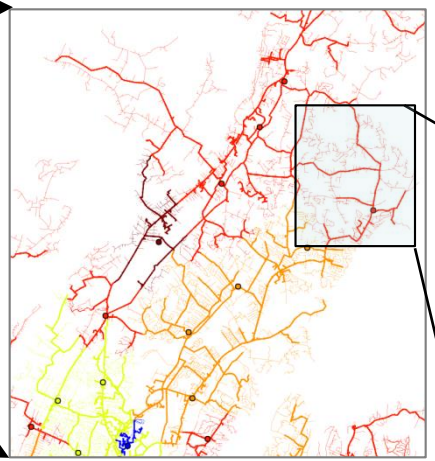
lower

higher

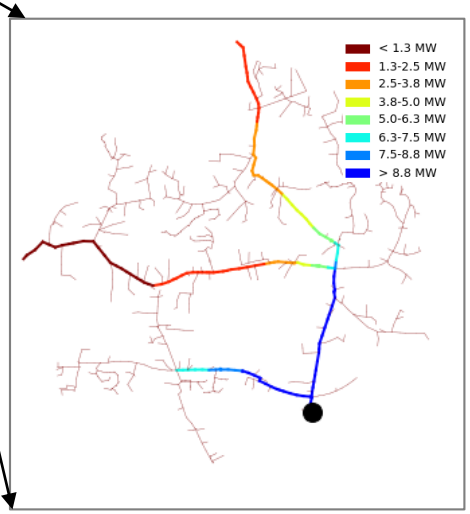
System Hosting Capacity
(~ 300 distribution feeders)



Substation-level Hosting Capacity



Feeder-level Hosting Capacity

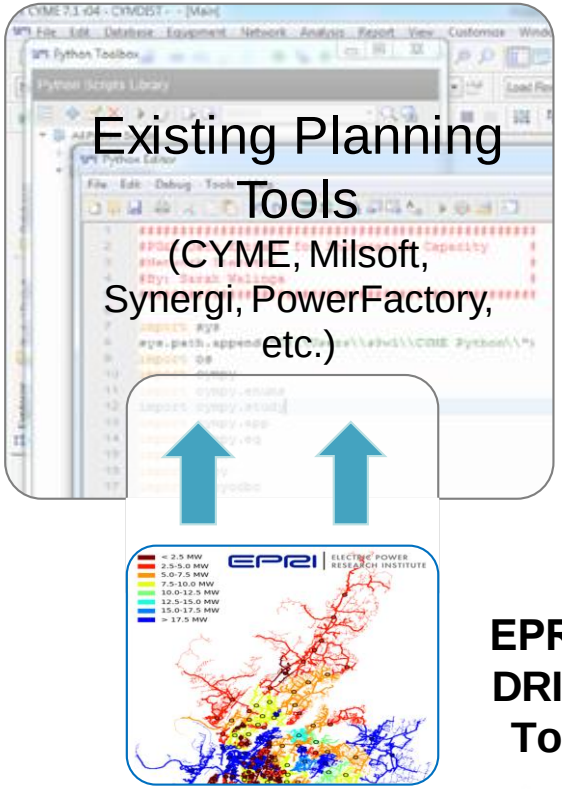


*Initial analysis results from TVA/ EPB study, results not finalized

Implementing the Hosting Capacity Method into Existing Distribution Planning Tools

- Distribution Resource Integration and Value Estimation (DRIVE) tool
- Rather than develop a new software tool, EPRI has focused efforts on implementation into existing planning tools
- Benefits of using existing planning tools
  - Necessary data resides in existing planning tools
  - Does not require "translating" data to other software platforms (requiring updating other software databases)
  - Can be used as part of toolset within planning tools for multiple purposes
    - Screening
    - Planning
    - Cost-benefit analysis

Incorporating EPRI's Hosting Capacity Method into existing utility planning tool



EPRI's DRIVE Tool

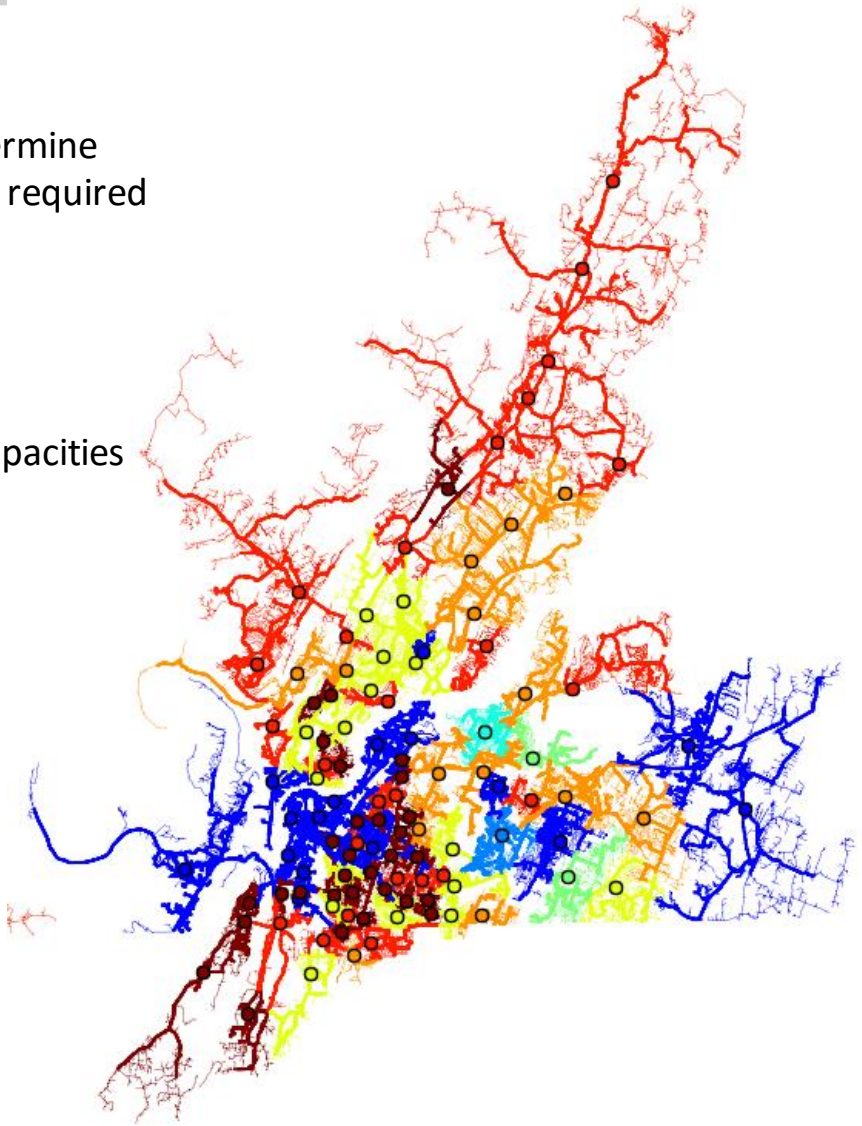
Increasing Hosting Capacity

Used EPRI's Streamlined Hosting Capacity method to determine feeder-specific DER impacts across system and mitigation required to increase hosting capacity

- DER considered: Distributed, Customer-based
- Issues considered (voltage, thermal, protection)

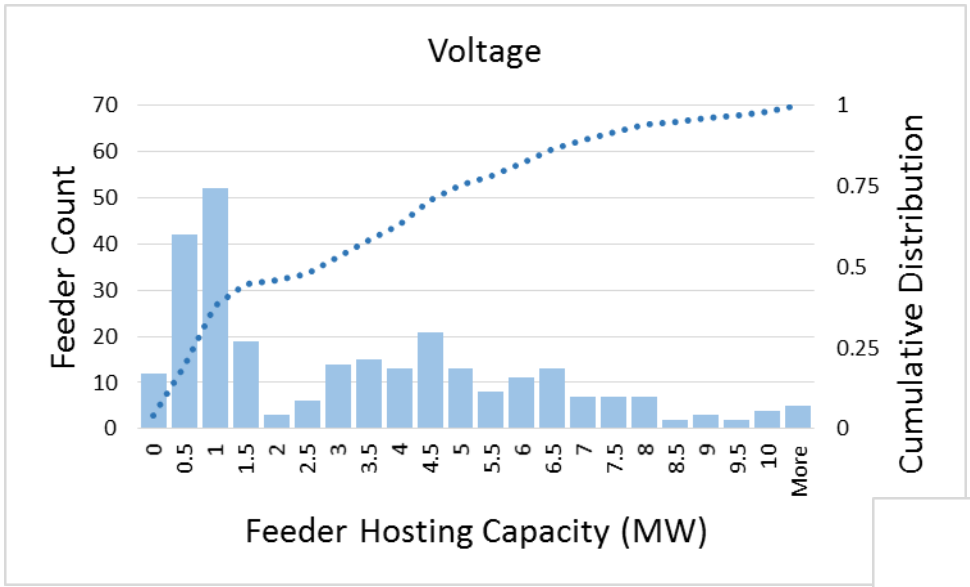
Estimated upgrades required to achieve higher hosting capacities (not all feeders required upgrades)

- Penetrations:
  - 0.5 MW
  - 1.0 MW
  - 2.0 MW
- Upgrades Utilized:
  - Power factor (inductive)
  - Reconductoring
  - Voltage class upgrade
  - Breaker relay replacement



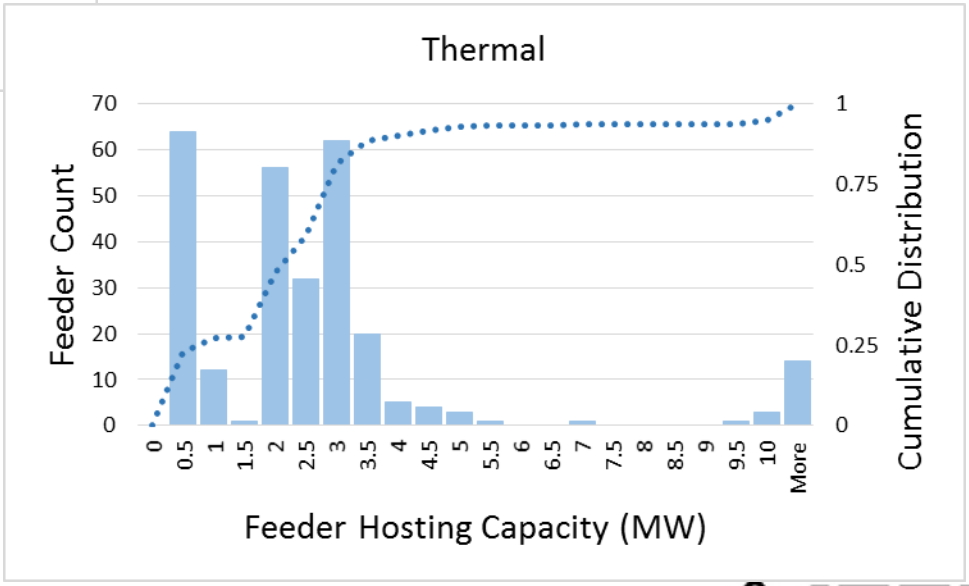
**A Framework for Determining the Technical and Economic Impacts of PV System Wide. EPRI, Palo Alto, CA: 2015. 3002005783*

Feeder Hosting Capacity Results



Each feeder has a unique hosting capacity response

- Some are voltage-constrained
- Others are thermal constrained

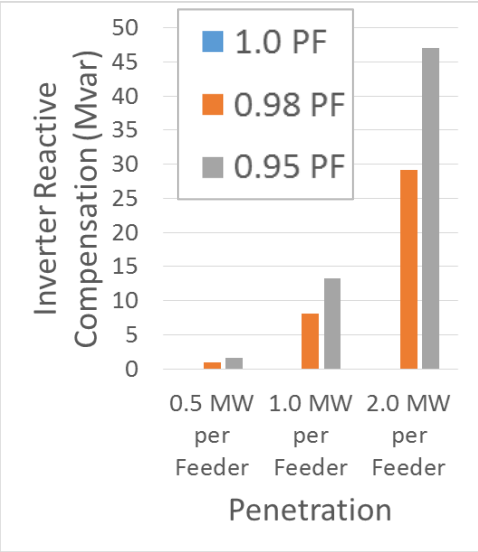


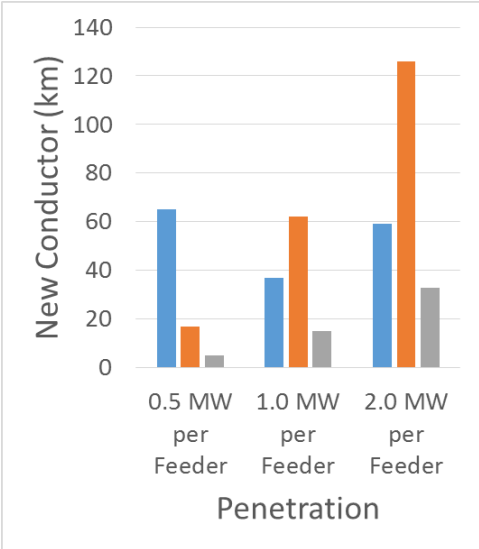
Methods for Increasing Distribution Hosting Capacity

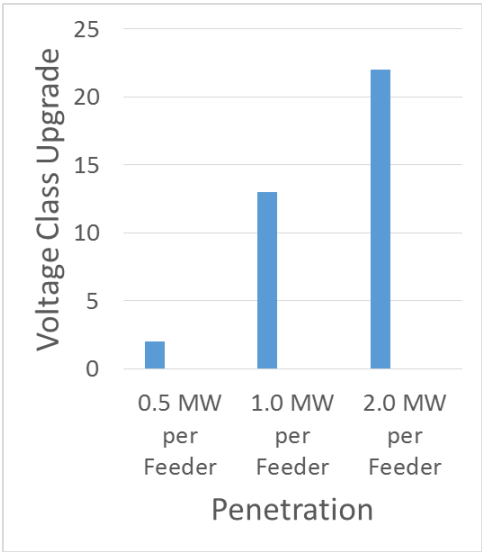
- Methods for increasing hosting capacity depend upon many factors
  - Limiting power system criteria
  - Distribution system design and operating characteristics
  - DER capabilities
- A single solution/technology does not resolve all issues
  - Voltage
  - Thermal
  - Protection
- Solutions can be situation-specific
  - E.g., smart inverters and reconductoring can help with voltage issues but not protection
- Solutions for increasing hosting capacity can have other benefits as well
  - Reconductoring and voltage uprating can reduce losses and increase load-serving capability
  - Comm/control of DER coordinated with existing controls can help regulate voltage

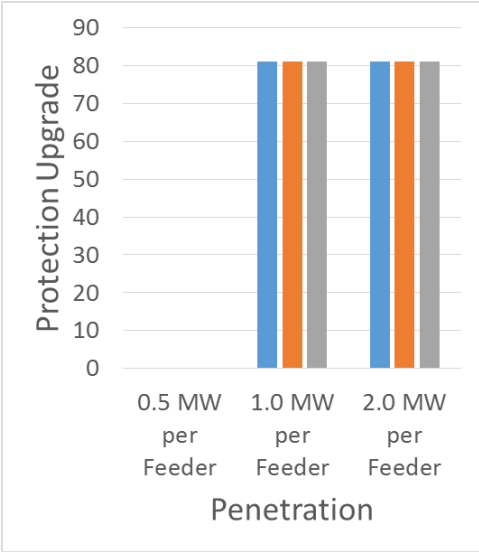
- Grid-Side Enhancements/Changes
  - Reconductoring
  - Voltage uprating
  - Transformer replacement
  - Additional voltage regulator
  - Comm/control (curtailment)
  - Additional relaying
  - Storage
- Operational Changes
  - Voltage regulation changes (LTC setpoint adjustment, etc.)
  - Relay setting modification
- Technology Solutions
  - Smart inverters (var and/or watt control)
  - Distributed var control
  - Energy storage
  - PV panel orientation
  - Demand response

Feeder Mitigation Summary





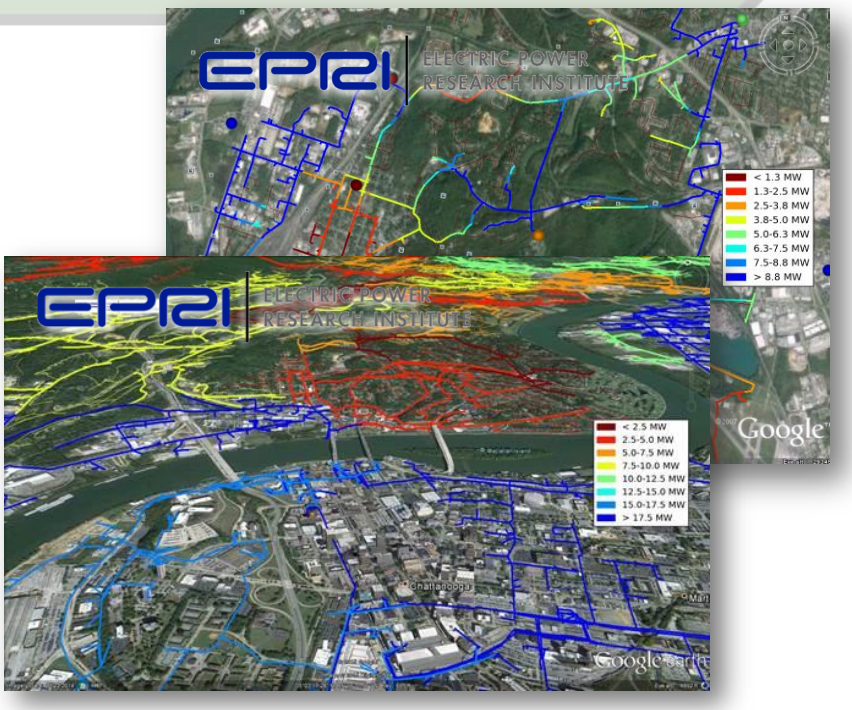


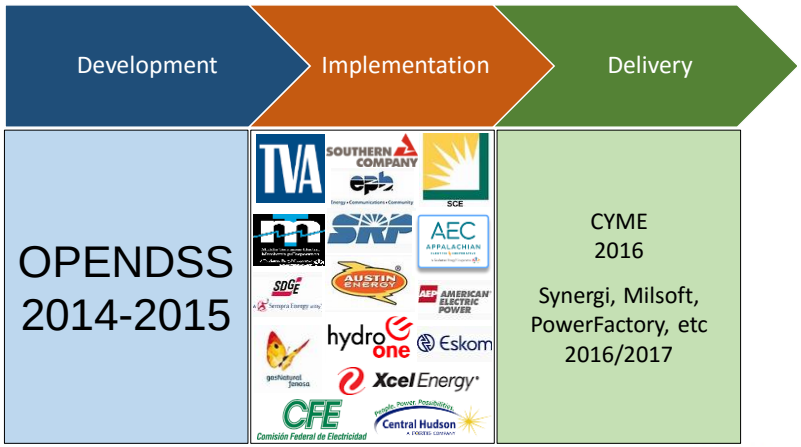


- Mitigation is applied in this order
  - Smart inverter
  - Reconductoring
  - Voltage class upgrade
  - Protection upgrade
- The penetration levels shown at left represent all feeders in the system
- More mitigation is required to attain higher penetration levels

Summary

- Hosting capacity analysis captures necessary impacts of DER
- Hosting capacity can be calculated different ways
- Streamlined methods are appropriate for system-wide analysis
- Hosting capacity can be determined within existing planning tools
- EPRI is currently working with software vendors for incorporation into distribution planning tools (CYME, Synergi, Milsoft, PowerFactory)





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Detailed Hosting Capacity Method

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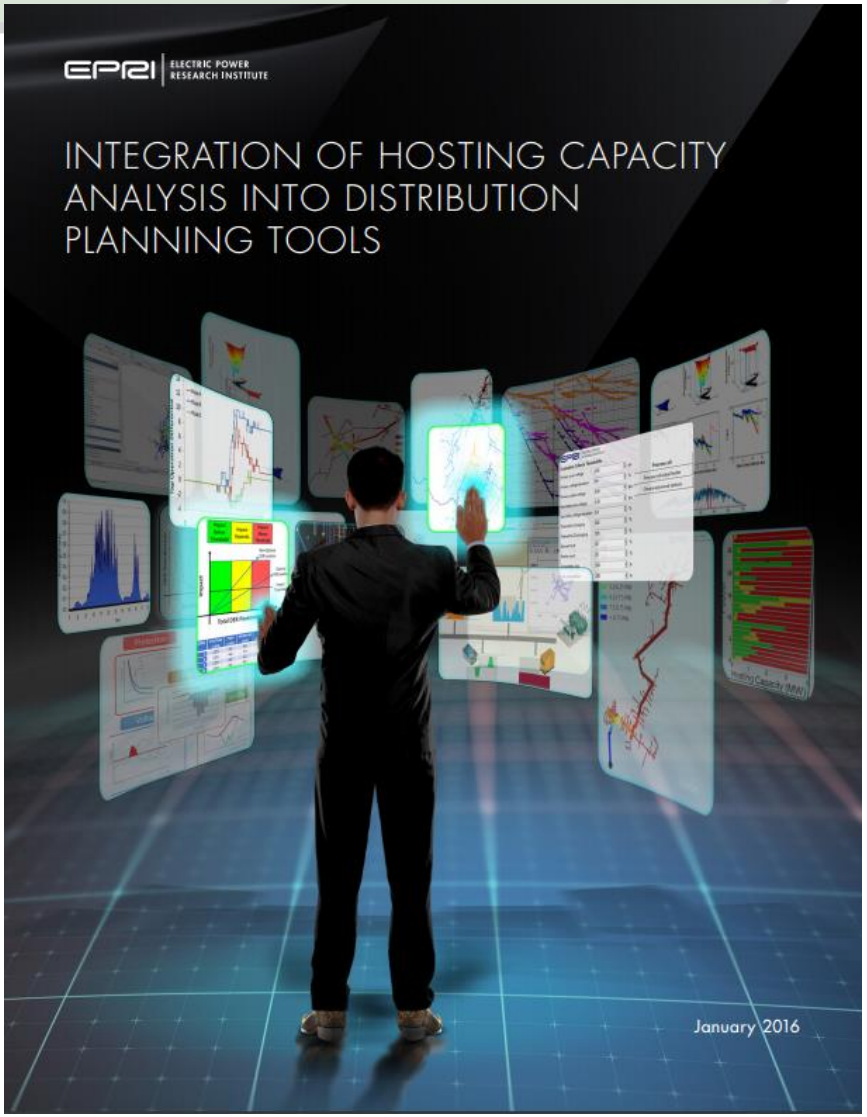

White Paper

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Questions

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