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EPIC Final Report

Program	**Electric Program Investment Charge (EPIC)**
Administrator	**San Diego Gas & Electric Company**
Project Number	**EPIC-1, Project 4**
Project Name	**Demonstration of Grid Support Functions of Distributed Energy Resources (DER)**
Module Name	**Module 3, Pre-Commercial Demonstration of the EPRI DRIVE Tool**
Date	**December 31, 2017**

Attribution

This comprehensive final report documents the work done in this EPIC project.

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Executive Summary

The objective of EPIC-1, Project 4, Demonstration of Grid Support Functions of Distributed Energy Resources (DER) was to demonstrate grid support functions of DER, which can improve distribution system operations. The chosen sub-projects and modules quantified the value of specific grid support functions in specific application situations and provided a basis for San Diego Gas & Electric Company (SDG&E) to determine which functions it wants to pursue commercially in the development of its smart grid. This project consists of three modules: value assessment of grid support functions of DER, communication standards for grid support functions of DER, and demonstration and comparison of the Electric Power Research Institute (EPRI) and SDG&E DER hosting capacity analysis tools. This executive summary addresses the module on pre-commercial demonstration of EPRI's Distribution Resource Integration and Value Estimation (DRIVE) tool, in comparison to SDG&E's Iterative Integration Capacity Analysis (ICA) tool.

Utilities are faced with making decisions on how to consider the growing penetration of DER on their system. With this challenge in mind, utilities across the country are beginning to look at how to meet the new requirements with analytical methods to identify impacts of distributed resources in the electric system. A foundational element of planning in the future is the capability to assess how much DER capacity the distribution system can "host." ***Hosting capacity is defined as the amount of DER that can be accommodated without adversely impacting power quality or reliability under existing control configurations and without requiring infrastructure upgrades.***

In California, the requirement to assess DER has come in the form of the California Legislature Assembly Bill (AB) 327, California Public Utilities Code (PUC) Section 769.[1] In response to this legislation, each investor owned utility (IOU) submitted a Distribution Resource Plan (DRP) that includes hosting capacity.[2] Pacific Gas and Electric Company (PG&E) responded with a "streamlined" hosting capacity approach, while SDG&E and Southern California Edison (SCE) responded with an "iterative" method. Table 3 summarizes the current methods used both in California and other jurisdictions.

Table 1. Hosting Capacity Methods

Method	Approach	Computation Time	Recommended Use Case	Industry Adoption
Stochastic	+Increase DER randomly +Run power flow for each solution	Hours	DER planning	PEPCO ComEd
Iterative (Integration Capacity Analysis)	+Increase DER at specific location +Run power flow for each solution	Hours*	Inform screening process and developers	SCE SDG&E
Streamlined	+Limited number of power flows +Utilizes combination of power flow and algorithms	Minutes	Inform screening process and developers	PG&E
DRIVE	+Limited number of power flows +Utilizes combination of power flow and algorithms	Minutes	DER planning, inform screening process and developers	>25 utilities worldwide

* ICA Iterative hosting capacity analysis has been previously stated as 27 hours per feeder

To date, industry adoption of these methods has been broad. Utilities are using hosting capacity as a foundational element to perform mapping, interconnection, system planning, and locational value studies.[3]

This activity is an element of the SDG&E Electric Program Investment Charge (EPIC) 1 - Project 4 on "Demonstration of Grid Support Functions of DER." The overall objective of the EPIC project is to validate the viability of specific DER functions and to identify which, if any, grid support functions of DER and application situations should be pursued commercially.

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[1] http://www.cpuc.ca.gov/General.aspx?id=5071

[2] The term hosting capacity and integration capacity are interchangeable. This report will use the industry adopted terminology.

[3] Defining a Roadmap to Successful Implementation of a Hosting Capacity Roadmap in NY State. EPRI. Palo Alto, CA: 2016. 3002008848.

The focus of this portion of the project was to perform a demonstration of EPRI's Distribution Resource Integration and Value Estimation (DRIVE) tool for determining the DER hosting capacity capabilities of distribution feeders. The resulting hosting capacity values provide a comparison to understand how similar the results are to the SDG&E iterative ICA. This project provides insights into two different methods and provides the first comparative analysis between the SDG&E Iterative method and DRIVE.

The demonstration is applied on five SDG&E feeders while considering voltage and thermal impacts.[4] The results of the iterative method align very closely to the results of DRIVE (See Figure 1 for sample results). This comparison, similar to the one done as part of the CA DRP Demo, provides a relative precision[5] to a third approach.

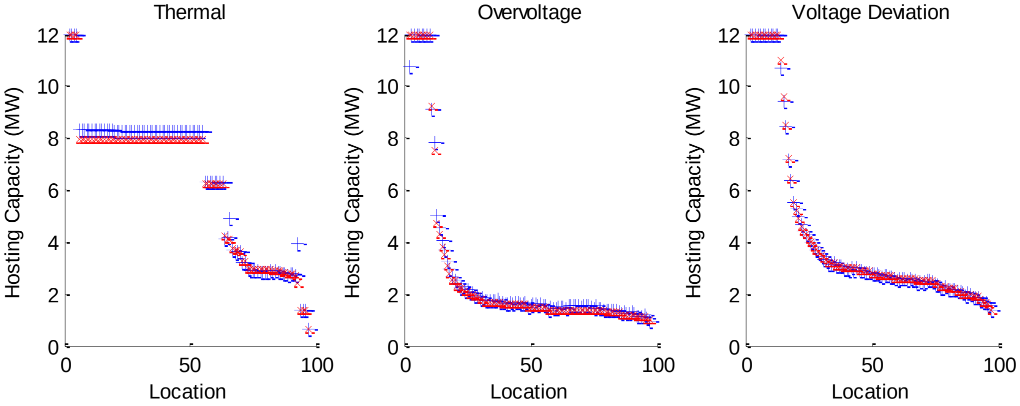

Figure 1. Comparative Results for One Feeder (Blue +: Iterative Analysis, Red x: DRIVE Analysis)

The comparative analysis also points to differences and areas that require continued improvement in both approaches as well as areas for further investigation as described in Table 2.

Table 2. Areas on Improvement/Understanding in Hosting Capacity Methodologies

Iterative	DRIVE
Further examination of inconsistencies in thermal analysis	Further examination of impedances used in voltage analysis
Consider including locking regulation equipment in voltage analysis	Incorporate branch analysis in voltage analysis
Further examination of inconsistencies in voltage deviation analysis	Further examination of impact of losses in voltage deviation analysis
Further examination of applied pre-existing violations	Consider inclusion of adjacent feeders at substation

This project demonstrated the use of the DRIVE tool for doing hosting capacity assessments on five selected SDG&E feeders. The results found both opportunities for implementation and challenges that require further investigation.

Key findings and recommendations are as follows:

Findings: Different hosting capacity methods can provide similar results; similar hosting capacity results can be derived more efficiently; hosting capacity methods will continue to evolve and improve.
Recommendations: SDG&E should keep DRIVE available as one of the tools it can use in future hosting capacity analyses; SDG&E should monitor the future advances in DRIVE and the emergence of other tools, to be able to make the best choices for specific future assessment needs.

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[4] Protection impact analysis is excluded from the comparative study as this is not currently performed using the ICA module in the Synergi power flow tool which SDG&E uses for voltage and thermal analysis.

[5] Comparative analysis to date has assessed relative precision in producing similar results. This is different than accuracy.

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List of Acronyms

Assembly Bill (AB)
California Public Utilities Code (PUC)
Distributed Energy Resources (DER)
Distribution Resource Integration and Value Estimation (DRIVE)
Distribution Resource Plan (DRP)
Electric Power Research Institute (EPRI)
Electric Program Investment Charge (EPIC)
Integration Capacity Analysis (ICA)
Investor Owned Utility (IOU)
Pacific Gas & Electric (PG&E)
San Diego Gas & Electric (SDG&E)
Southern California Edison (SCE)

1.0 Introduction

1.1 Statement of project objective

This activity is an element of San Diego Gas & Electric Company's (SDG&E's) EPIC 1 - Project 4 on Demonstration of Grid Support Functions of Distributed Energy Resources (DER). The overall objective of the EPIC project is to validate the viability of specific DER functions and to identify which, if any, grid support functions of DER and application situations should be pursued commercially. This activity is complementary to another activity already in progress, as part of this project.

The focus of this portion of the project was to perform a demonstration of the Electric Power Research Institute's (EPRI's) Distribution Resource Integration and Value Estimation (DRIVE) tool for determining the DER hosting capacity capabilities of distribution feeders. The hosting capacity values resulting from this demonstration provide a comparison to understand how similar the results are to the SDG&E iterative integration capacity analysis (ICA). This project provides insights into two different hosting capacity methods and provides the first comparative analysis between the iterative method used in SDG&E and that of DRIVE.

1.2 Summary of the project scope of work

Utilities are faced with making decisions on how to consider the growing penetration of DER on their system. The result is a new set of challenges for planning and operating the grid that serves these new resources. With this challenge in mind, utilities across the country are beginning to look at how to meet the new requirements with analytical methods to identify impacts of distributed resources in the electric system. A foundational element of planning the distribution system of the future is the capability to assess how much DER capacity the distribution system can "host."

Hosting capacity is defined as the amount of DER that can be accommodated without adversely affecting power quality or reliability under existing control configurations and without requiring infrastructure upgrades.

In California, the requirement to assess DER has come in the form of the California Legislature Assembly Bill (AB) 327, California Public Utilities Code (PUC) Section 769.[6] In response to this legislation, each investor owned utility (IOU) submitted a Distribution Resource Plan (DRP) that encompasses, among other items, hosting capacity.[7] Pacific Gas and Electric Company (PG&E) responded with a "streamlined" hosting capacity approach, while SDG&E and Southern California Edison (SCE) responded with what is referred to as an "iterative" method. Table 3 summarizes the current methods used to estimate hosting capacity both in California and in other jurisdictions including the advantages and disadvantages of each method.

Table 3. Hosting Capacity Methods

Method	Approach	Advantages	Disadvantages	Computation Time	Recommended Use Case	Industry Adoption
Stochastic	+Increase DER randomly +Run power flow for each solution	+Similar in concept to traditional interconnection studies +Becoming available in planning tools	+Computationally intensive +Limited scenarios	Hours	+DER planning	PEPCO ComEd
Iterative (Integration Capacity Analysis)	+Increase DER at specific location +Run power flow for each solution	+Similar in concept to traditional interconnection studies +Becoming available in planning tools	+Computationally intensive +Limited scenarios +Vendor-specific	Hours*	+Inform screening process +Inform developers	SCE SDG&E

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[6] http://www.cpuc.ca.gov/General.aspx?id=5071

[7] The term hosting capacity and integration capacity are interchangeable. This report will use the industry adopted terminology of hosting capacity.

			implementations can vary			
Streamlined	+Limited number of power flows +Utilizes combination of power flow and algorithms	+Computationally efficient +Not vendor tool specific	+Novel approach to hosting capacity +Not well understood method +Limited scenarios +Not available in current planning tools	Minutes	+Inform screening process +Inform developers	PG&E
DRIVE	+Limited number of power flows +Utilizes combination of power flow and algorithms	+Computationally efficient +Many DER scenarios considered +Not vendor tool specific +Broad utility industry adoption and input +Becoming available in planning tools	+Novel approach to hosting capacity +Not well understood method +Lag between modifications/ upgrades and associated documentation	Minutes	+DER planning +Inform screening process +Inform developers	>25 utilities worldwide

* ICA Iterative hosting capacity analysis has been previously stated as 27 hours per feeder[8]

To date, industry adoption of these methods has been broad. Utilities are using hosting capacity as a foundational element to perform the following:[9]

- **Mapping:** Having a defined hosting capacity method gives developers/customers the ability to understand better/worse locations for DER on the system as an indicator of potential costs. Important considerations for this application are that maps only illustrate a point in time in a dynamic system – both as new applications are approved and the system operational requirements change.
- **Interconnections:** Hosting capacity information helps guide power systems engineers where detailed engineering studies are less likely to be required, improving efficiency of the process. There are some challenges in the frequency of updates to this data.
- **System Planning:** Hosting capacity analysis is also becoming a critical piece in the analytical framework and methodologies needed for integrated planning. Hosting capacity can be enhanced with load and DER forecasts to evaluate different planning scenarios on a feeder-by-feeder basis.
- **Locational Value:** The data, tools, and processes utilized in hosting capacity analysis can also help identify locations where benefit from DER can be maximized without incurring additional costs.

While these hosting capacity methods have advantages and disadvantages, most critical to the resulting values are the impact factors. Hosting capacity assessments should consider a wide range of impact factors including both DER and grid side impacts. The range of DER a feeder can host depends on the location and characteristics of both the feeder and DER. For DER impact factors, there are several characteristics that must be considered including location, type, control capabilities, aggregation of DER, and portfolios of different DER technologies. For grid impact factors, important characteristics to consider include voltage control, configuration, load, and phasing. Table 4 provides a summary of these impact factors with a relative ranking of importance in the impact they have on the resulting hosting capacity.

Given this landscape, this project demonstrated the DRIVE hosting capacity methodology on five SDG&E feeders to quantify the amount of DER each feeder can host without causing adverse impacts. The results of this analysis have been compared with the iterative method implemented by SDG&E in their DRP to better understand similarities and

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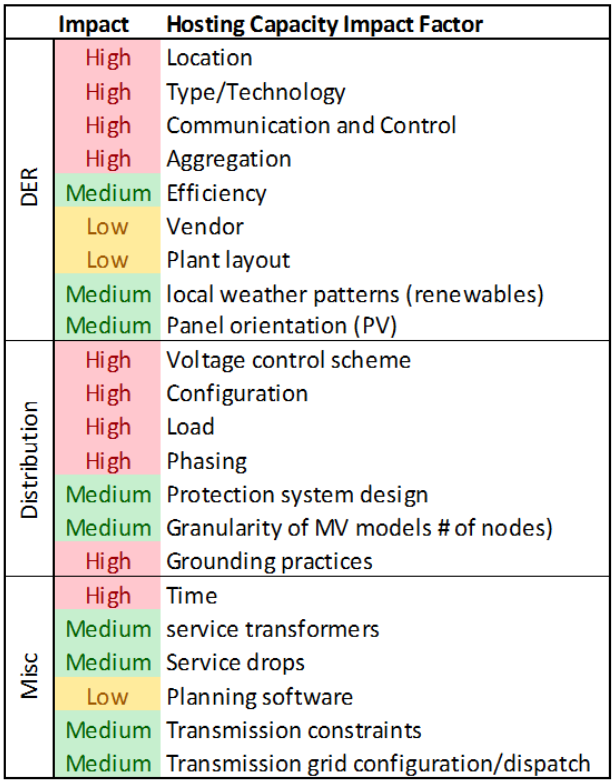
[8] http://drpwg.org/wp-content/uploads/2016/07/R.14-08-013-DRP-Demos-A-B-Reports-SDGE.pdf

[9] Defining a Roadmap to Successful Implementation of a Hosting Capacity Roadmap in NY State. EPRI. Palo Alto, CA: 2016. 3002008848.

differences. This report summarizes the results of that demonstration and provides recommendations based on the findings.

Table 4 Relative Effect of Hosting Capacity Impact Factors



	Impact	Hosting Capacity Impact Factor
DER	High	Location
	High	Type/Technology
	High	Communication and Control
	High	Aggregation
	Medium	Efficiency
	Low	Vendor
	Low	Plant layout
	Medium	local weather patterns (renewables)
	Medium	Panel orientation (PV)
Distribution	High	Voltage control scheme
	High	Configuration
	High	Load
	High	Phasing
	Medium	Protection system design
	Medium	Granularity of MV models # of nodes)
	High	Grounding practices
Misc	High	Time
	Medium	service transformers
	Medium	Service drops
	Low	Planning software
	Medium	Transmission constraints
	Medium	Transmission grid configuration/dispatch

1.3 Description of major tasks, milestones, and deliverables

This project has six tasks with three major activities to meet the stated objectives. The main activities are Feeder Identification and Methodology Settings, Data Collection, and DRIVE demonstration for Hosting Capacity Assessment. Table 5 provides a brief summary of the project tasks and milestones. The text that follows provides details on approach and assumptions important to research findings.

Table 5. Project Tasks, Objectives, and Deliverables

Task	Objective
Task 1 Kickoff meeting, stakeholder consultations, and work plan review	Initiate the project, identify key stakeholders and to develop the detailed work plan for the project.
Task 2 Feeder Identification and Methodology Settings	Identify feeder models and settings for the demonstration and analysis.
Task 3 Data Collection	Obtain the necessary data for the demonstration.
Task 4 Demonstrate DRIVE for Hosting Capacity Assessment	Demonstrate DRIVE for hosting capacity analysis on selected use cases. Compare results to the SDG&E iterative analysis.
Task 5 Workshop	Conduct a workshop with SDG&E to review results, get feedback and input, and train SDG&E on using DRIVE.
Task 6 Comprehensive Final Report	Develop a comprehensive final report on the project work.

First, EPRI and SDG&E worked together to identify appropriate feeders for analysis. Five feeders were selected based upon their design configurations (long rural, short urban, heavy commercial/industrial). In order to compare hosting capacity methodologies, EPRI and SDG&E worked together to identify all analysis settings. To conduct a similar analysis, some settings were modified as necessary. These settings include items such as allowable feeder impact (like maximum allowable voltage) and DER characteristics (like resource variability).

Once feeders were selected and parameters set, SDG&E shared the model data for analysis. This included feeder models containing voltage regulation equipment and settings (LTC, line regulator, and switched capacitor) as well as existing DER.

EPRI and SDG&E both executed the hosting capacity analysis on the set of feeders with the agreed upon parameters - EPRI utilized the DRIVE hosting capacity analysis method and SDG&E utilized the Synergi[10] iterative method. The focus of the analysis was on the voltage and thermal impacts.[11] The results of this analysis were then compared and summarized in this report.

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[10] https://www.dnvgl.com/services/power-distribution-system-and-electrical-simulation-software-synergi-electric-5005

[11] Protection comparison was not considered in this analysis as those calculations are currently not performed using the ICA module in the Synergi power flow tool which SDG&E uses for voltage and thermal analysis.

2.0 Project Approach

2.1 Methods for Comparison[12]

Given that different methods/tools are used, the hosting capacity results can be expected to be different. However, if hosting capacity analysis parameters, models, and impact factors used by the different tools are the same, one would expect the hosting capacity results to be similar. It is imperative that these factors are consistent in both methodologies when comparing the results to ensure any differences are based on methodology and not the input data or assumptions. To ensure this, EPRI and SDG&E ran the demonstration in parallel on the same set of feeders using the same models and inputs. The two methods used for the demonstration are further described below to provide context to the differences in approach, complexity, and time.

2.1.1 SDG&E Iterative ICA Method

The iterative method[13,14] used in SDG&E's ICA is a technique similar to that which has been used over the past few years to quantify the impacts of DER on distribution systems. DER is modeled directly at single locations, one at a time, while DER capacity is increased until issues occur on the system.

The iterative method essentially performs power flow simulations with DER at user-selected three-phase locations on the distribution system. Using this method, varying levels of DER are simulated at each location independently with power flow simulations iteratively performed to determine the maximum level of DER that can interconnect at these locations without exceeding thermal and voltage limits. Figure 2 depicts the iterative method technique in simplified diagram.

In addition to the power flow simulations, which are used primarily to evaluate thermal and steady state voltage conditions, fault flow simulations are also performed. The fault flow simulations are used to evaluate the protection criteria and to determine the DER level that can be interconnected to each node without hindering the protection devices' ability to detect fault conditions. Note, protection analysis was not included in this comparative study as this portion of the ICA is algorithm-based and does not leverage the Synergi-implemented iterative approach.

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[12] *Methods and Considerations for Applying Hosting Capacity*. EPRI, Palo Alto, CA, 2017: 3002011009

[13] Southern California Edison Company's (U 338-E) Demonstration Projects A and B Final Reports, December 23, 2016

[14] Demonstration Projects A&B Final Reports of San Diego Gas & Electric Company (U 902-E), December 22, 2016

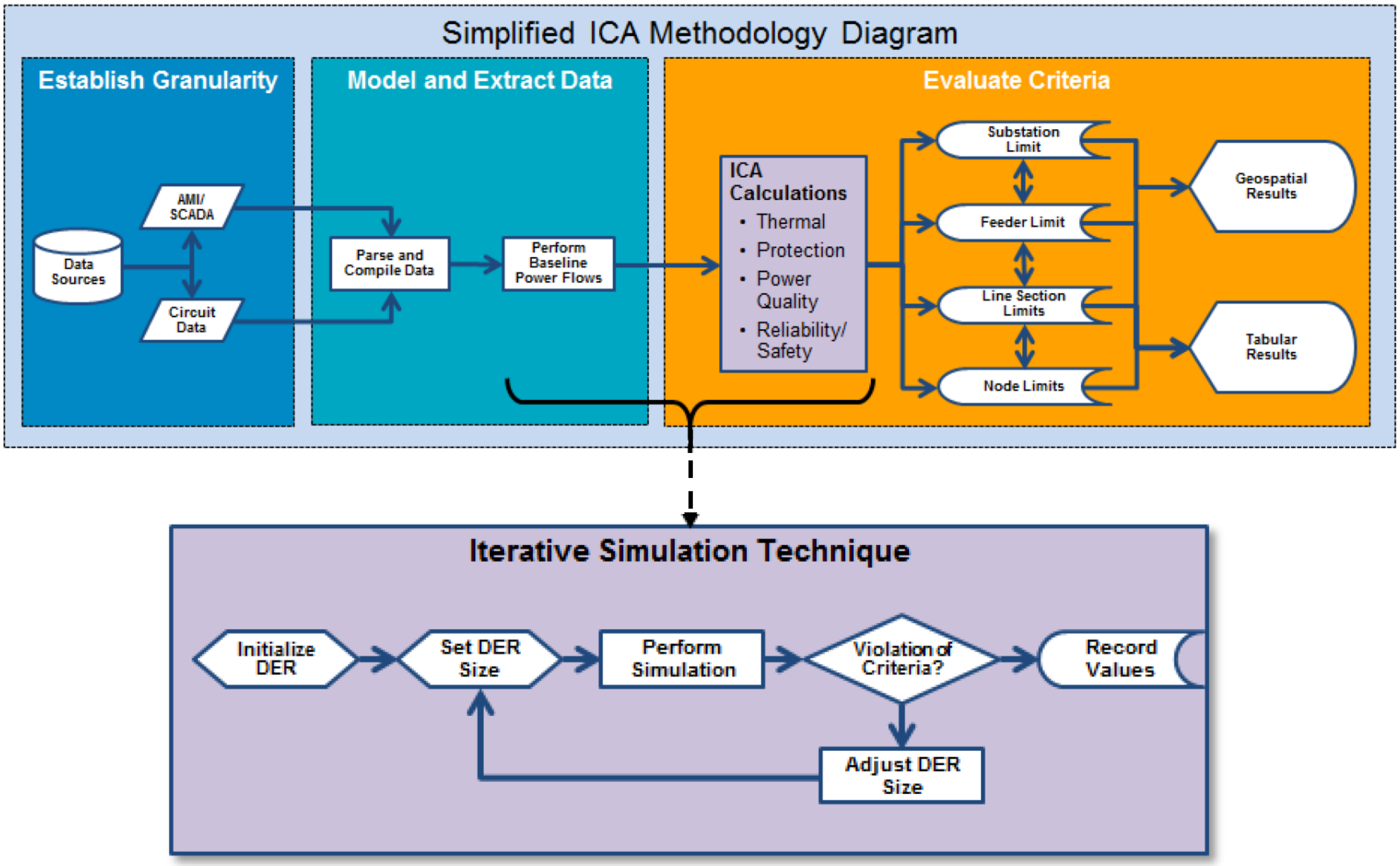

Figure 2. Simplified Diagram of the Iterative Method

This process is repeated for multiple time intervals (576 representative hours) to try to capture daily changes in load, DER, and regulation equipment, and observe their impacts on hosting capacity. This creates a form of time-based hosting capacity. The time series data needed to create these models are derived from 8760 hour DER and load forecasts leveraging historical smart meter data. The derived time series data consists of twenty-four sets (12 months x 2 days) of 24-hour profiles. For each month, there are 2 days that are derived as:

1. 90th percentile representing the high load scenario
2. 10th percentile representing the low load scenario

Evaluating all 576 unique load points is intended to understand the range of hosting capacities based on day and time. For the data to be leveraged into a time-series analysis where the voltage regulation and control from one time interval influences the next time period, the 576 load points are used as a single load profile. This time-series profile, however, is based on a discontinuous set of data as high load days do not transition directly into the low load days of each month. Therefore, the purpose of the time-series analysis, to capture accurate voltage regulation, should be further considered.

An important step in the process is the concept of layered abstraction representing divisions of the electric system in a top down fashion. The analysis looks at various layers of the system and ensures that the higher-level layers impact or limit the lower layers when applicable. By defining layers that represent the electric system hierarchy, explicit criteria calculations can be made within each layer independent of another layer’s calculation. This helps organize the results in a way that can inform specific limitations to a single point of interconnection or broader limitation to a feeder or substation.

This point is illustrated in Figure 3 where the process of evaluation can be seen across the criteria at each layer. This approach is important to obtain results from node-specific limitations all the way to transmission-specific limitations. For instance, locational results can be limited by a higher-level constraint such as the thermal limitation of a substation transformer, therefore limiting the total amount of possible DER that can be interconnected on the downstream feeders, nodes and line sections.

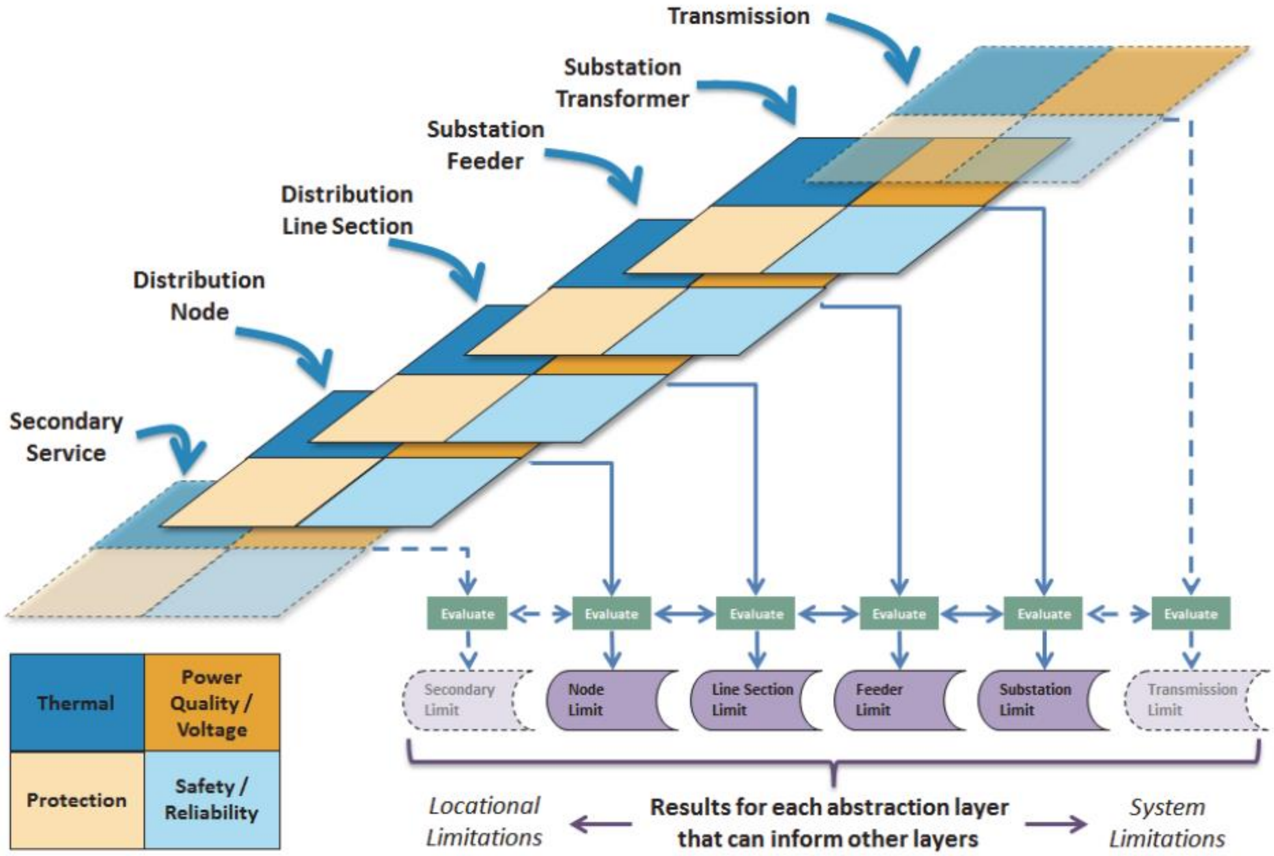

Figure 3. Illustration of Layered Abstraction Process

Once the layered abstraction approach is applied, time-based hosting capacity values for all 576 time intervals are derived resulting in what is referred to as an agnostic hosting capacity for the metrics identified in Table 6.

Table 6. ICA Hosting Capacity Metrics Determined per Location

Hosting Capacity Metrics	DER Scenario Allowing Reverse Power Flow	DER Scenario Limited by Reverse Power Flow
voltage due to generation	X	X
voltage due to load	X	X
voltage deviation due to generation	X	X
voltage deviation due to load	X	X
thermal due to generation	X	X
thermal due to load	X	X
reverse power flow		X
breaker reach	X	
additional fault current	X	
operational flexibility	X	

2.1.1.1 Assumptions

A number of assumptions are made within each method and the list below attempts to capture some of those pertinent to hosting capacity results. As methods further evolve over time, so will the associated assumptions.

- A DER agnostic hosting capacity can be determined and later decoupled into a DER specific hosting capacity portfolio
- Voltage regulation (LTC, line regulator, capacitor) is allowed to operate to adjust for DER impacts.[15]
- The impact of existing DER on voltage deviation is not considered. For example, voltage deviation calculations assume not all existing DER devices contribute to voltage changes (fixed output). In some cases, this can overestimate hosting capacity.
- Time series analysis captures accurate voltage regulation and control operations. The time-series profiles are based on a reduced set of discontinuous data as high load days do not transition directly into the low load days of each month. EPRI recommends the use of a reduced set of data, but it should be acknowledged that any reduction in data nevertheless streamlines the analysis.
- All ICA hosting capacity results are determined using the full detailed model and power/fault flow analyses. To reduce simulation times, some calculations may be performed using alternative methods to streamline the analysis.

2.1.2 EPRI DRIVE Method

The DRIVE hosting capacity method is the successor to the stochastic-based approach previously developed by EPRI. This method was developed to overcome the computation burden of stochastic and iterative-based approaches while still capturing critical grid responses for determining location-based hosting capacity.

Initially developed as a PV hosting capacity method,[16] this method has been further refined and updated as a DER technology neutral approach thus allowing other distributed technologies to be considered based on resource characteristics such as fault current contribution and output variability. The specific technology determines how the analysis is setup to properly quantify the unique impacts of the particular resource.

Working with a number of utilities throughout the world, further enhancements and refinements have been made to the initial approach to add new capabilities, improve overall accuracy, and increase efficiency.[17] A DRIVE User Group has been created to facilitate this process.

2.1.2.1 Overview

The method behind the DRIVE tool is similar to PG&E's streamlined method in concept - where a select number of power flow cases are used to characterize the feeder response, and then calculations are performed to determine DER scenario impacts and hosting capacities. However, the underlying approach and equations are different.[18]

There are two components in EPRI's DRIVE tool as shown in Figure 4. The first component is the Interface to the Planning Tool Module. In this component, each feeder is analyzed to extract information from the model via power flows and short circuit studies. The second component is the DRIVE Hosting Capacity Assessment Module where the extracted data from the first component is analyzed and examined for Hosting Capacity. More detail regarding the underlying method has previously been documented.[19]

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[15] Allowing regulation equipment to operate can overestimate hosting capacity in some cases, particularly when the intermittent DER (solar, wind, storage) operates faster than regulation equipment. Quantifying this impact requires simulations to be ran in the 5-30 seconds timeframe rather than hourly as in the ICA. [Ref: Time Series Power Flow Analysis for Distribution Connected PV Generation, Sandia National Laboratory, SAND2013-0537, 2013]

[16] A New Method for Characterizing Distribution System Hosting Capacity for DER: A Streamlined Approach for PV. EPRI, Palo Alto, CA: 2014. 3002003278.

[17] *Distribution Resource Integration and Value Estimation (DRIVE) Tool: Advancing Hosting Capacity Methods to Include Existing DER and Reactive Power Control*. EPRI, Palo Alto, CA: 2016. 3002008293.

[18] Direct comparison of results from the two methods have not been performed to date.

[19] *Distribution Planning with DER: System-Wide Assessment*. EPRI, Palo Alto, CA: 2017. 3002010356

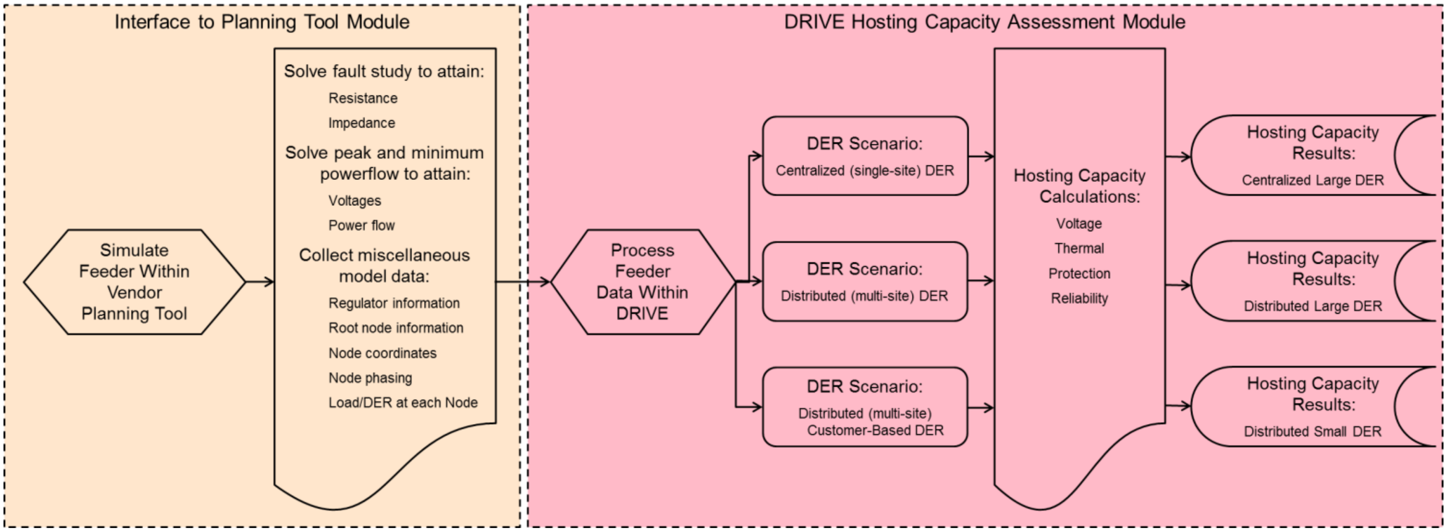

Figure 4. Components of DRIVE

2.1.2.2 Interface to Planning Tool Module

The interface to the planning tool module extracts important data out of the planning tool and models. These interfaces are compatible with a wide range of planning tools (CYME, Synergi, Milsoft, Powerfactory, OpenDSS, Gridlab-D, DEW, PVL, etc.).

The feeder models, exactly as the utility maintains, are analyzed with a limited set of power flows. These load levels are typically chosen based on peak and minimum. These two load levels create boundary conditions for the feeder, which are essential to the analysis of thermal and voltage impacts. For DER types such as photovoltaics, these load levels can be adjusted to daytime hours. The user ultimately has the capability to analyze more or less than two load levels for any one feeder.

The initial power flows are also conducted without any currently connected DER. This is done to determine the baseline operating point of each feeder without DER. Information about the connected/existing DER (if any) is extracted and sent to the Hosting Capacity Assessment where the user has the option to determine the feeder's total or remaining hosting capacity. Conditions might exist wherein the existing DER has direct control from the system operator and thus existing DER should not limit the remaining feeder hosting capacity. Conversely, the existing DER might significantly limit the feeders remaining hosting capacity. As such, the method by which existing DER is treated in the hosting capacity analysis is based on the characteristics of the DER.

Within the Interface to the Planning Tool, the detailed feeder model is analyzed with a series of power flow and fault flow studies. The power flow study provides voltages, element loading, load allocation, and connectivity of the model, while the fault study provides impedance/resistance/reactance data.

2.1.2.3 DRIVE Hosting Capacity Assessment Module

The DER assessments are then performed by applying various DER "scenarios" based on current injection. The hosting capacity is then determined based on whether the specific condition exceeds a user-defined threshold (voltage, protection, thermal). These scenarios consider centralized (single-site) and distributed (multiple-site) DER locations. Thousands of scenarios are examined when considering all potential locations, or "nodes", on the distribution feeder, and are broken down into three main categories:

- Centralized (single site) DER
- Distributed (multi-site) DER
- Distributed (multi-site) Customer-Based DER (e.g., rooftop PV)

Centralized (single-site) DER: The hosting capacity scenario depicts how much DER at a specific location can be accommodated as shown in Figure 5. When the hosting capacity analysis is performed, each node on the feeder is considered independently. This analysis provides insight to the feeder's ability to accommodate DER as well as each individual node on the feeder.

Figure 5. Simplistic Illustration of Centralized DER Analysis

Distributed (multi-site) DER: The hosting capacity scenario depicts how much distributed DER can be accommodated. The distribution applied has Weibull characteristics where its shape and scale are based on the nodes of the feeder. The distribution is continuous, as shown in Figure 6, thus an incremental amount of DER is considered at each node on the feeder. The use of this distribution was developed based on detailed stochastic analysis.[20] When the hosting capacity analysis is performed, each node on the feeder is used to adjust the shape and scale of the applied DER distribution. This analysis provides insight to the feeder's ability to accommodate various deployments of multi-site DER.

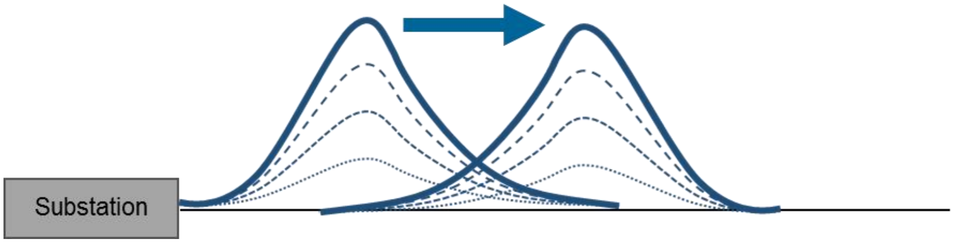

Figure 6. Simplistic Illustration of Distributed DER Analysis

Distributed (multi-site) Customer-Based DER: The hosting capacity scenario depicts how much distributed DER can be accommodated. The DER distribution is based on the location of existing customers and load on the feeder. The location of these customers are used to adjust the shape and scale of the applied DER distribution. Again, the use of this distribution was based on the detailed stochastic analysis previously referenced.

These scenarios make up the basis of the DER impact analysis. Each scenario results in a hosting capacity value and therefore there are multiple hosting capacities at each node – two based on Distributed DER and another based on Centralized DER. The metrics with hosting capacity results from the DRIVE analysis are shown in Table 7.

Table 7. DRIVE Hosting Capacity Metrics Determined per Location

Hosting Capacity Metrics	Centralized (single-site) DER	Distributed (multi-site) DER	Distributed (multi-site) Customer-Based DER
overvoltage due to generation	X	X	X
voltage deviation	X	X	X
regulator voltage deviation	X	X	X
undervoltage due to generation	X	X	X
undervoltage due to load	X	X	X

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[20] *Stochastic Analysis to Determine Feeder Hosting Capacity for Distributed Solar PV.* EPRI, Palo Alto, CA: 2012. 1026640.

thermal due to generation	X	X	X
thermal due to load	X	X	X
reverse power flow	X	X	X
additional fault current	X	X	X
breaker reach	X	X	X
sympathetic feeder tripping	X	X	X
unintentional islanding	X	X	X

2.1.2.4 Assumptions

A number of assumptions are made within each method and the below list attempts to capture some of those pertinent to hosting capacity results. As methods further evolve over time, so will the associated assumptions.

- DER considered as a constant current injection, such that fault currents considered in the analysis can be higher than if dependent on impedance to the actual fault. Constant current injection also implies DER current does not change during DER induced voltage rise. This can result in underestimation of hosting capacity for extreme voltage-rise scenarios.
- Load magnitude does not change when DER changes voltage (loads are based on initial power flow). This can result in slightly different load currents and feeder losses which local DER can supply.
- Voltage regulation equipment does not operate to mitigate voltage rise due to DER. Allowing voltage regulation equipment to operate can mask the voltage issues that DER could cause in some cases. EPRI considers voltage regulation a solution to increase hosting capacity and therefore it is not part of DRIVE that calculates the baseline hosting capacity before mitigation solutions are assessed.
- Existing DER is considered in the hosting capacity analysis of every metric.

2.2 Implementation Considerations

As is shown in the previous section, no two hosting capacity methodologies are the same. Inputs, outputs, and assumptions vary. Therefore, a challenge in this project revolved around applying the pre-developed methodologies such that results from those methodologies could properly be compared. There are underlying assumptions and techniques that, if not addressed, would pose inconclusive results. The underlying assumptions can also depend on the tools used to conduct the analysis. Fortunately, both the iterative and DRIVE analyses can be performed on the same SDG&E feeders, modeled within Synergi Electric.[21] The iterative hosting capacity results are provided directly from Synergi Electric, while DRIVE is a standalone tool that has an interface to the Synergi Electric feeder model. Some of the unique aspects of the two tools used in the study are shown in Table 8. Comments on how to address those aspects are included in the table and discussed in the text below.

Table 8. Differences in Methodologies

	DRIVE	**ICA Iterative**	**Comments**
DER Locations Analyzed	All feeder locations	User selected feeder locations*	**DRIVE will compare results at locations selected in the iterative analysis**
DER Scenarios Analyzed	Distributed (multi-site) and Centralized (single-site) DER hosting capacity scenarios	Centralized (single-site) DER hosting capacity scenario	**Compare Centralized (single-site) DER hosting capacity scenario**

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[21] https://www.dnvgl.com/services/power-distribution-system-and-electrical-simulation-software-synergi-electric-5005

Model Analyzed	Substation and Single Feeder Served	Substation and All Feeders Served	**Adjacent feeders on the substation bus will be aggregated to the substation bus for the DRIVE analysis. See following text.**
Load Level Considered	Two load conditions	576 load conditions	**DRIVE will analyze one load condition and those results will be compared to the same load condition of the iterative analysis.**
Hosting Capacity Metrics	Voltage, Thermal, Protection	Voltage and Thermal**	**Select voltage and thermal hosting capacities compared**

*Only 'Can Host DER' locations

**Protection is not calculated using the iterative approach

The most critical impact factor to a successful comparison is to have the same underlying feeder models. Besides the using the same underlying models in Synergi Electric, DRIVE processes feeder hosting capacity on a single feeder basis while the iterative method considers all feeders served off the substation bus simultaneously. Therefore, the iterative method might limit DER on the subject feeder due to impacts caused on the adjacent feeder. These adjacent feeder issues are commonly caused by allowing the voltage regulation to operate within the hosting capacity analysis. For instance, adding DER on the subject feeder might cause the LTC to tap down and cause an under voltage on the adjacent feeder. Again, as a fundamental component to DRIVE, voltage regulation adjustment is not considered in the analysis to establish baseline hosting capacity and voltage impacts to adjacent feeders are limited to the voltage impact at the point of common coupling (the substation bus). What should not be ignored, however, are the potential loading implications caused by the adjacent feeders. The load on the adjacent feeders will affect the LTC position and the total power flow through the substation transformer. To recognize this, the DRIVE analysis retains the aggregate load from the adjacent feeders at the substation bus.

The ICA iterative method produces hosting capacity results for 576 different time intervals. This equates to analyzing 576 different conditions for load and DER along with LTC and capacitor controls. To address this, the hosting capacity results for one time period of the iterative analysis was compared to the DRIVE results when analyzing only that same time intervals.

DRIVE automatically determines the Distributed and Centralized DER hosting capacities at every node/location on the feeder. A node is defined for each electrical section modeled in the feeder as shown in Figure 7. Since the iterative method results are for DER at the specific locations defined by the outward/downstream node of selected sections, the iterative results will be compared to the DRIVE results for Centralized DER at the same locations.

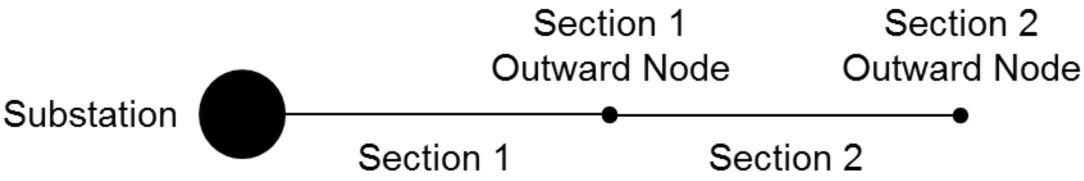

Figure 7. Definition of Node and Section

The Synergi ICA module used for voltage and thermal analysis currently does not support the determination of protection-based hosting capacity results (e.g., breaker reach, sympathetic tripping, etc.) that are performed in a full ICA analysis[22]. The metrics that are compared in this study are stated in Table 9. For consistency, the DER characteristics for which the hosting capacity analysis is performed assumes DER is set for unity power factor with full 100% power output swings. The maximum penetration considered for hosting capacity is 12 MW.

Table 9. Hosting Capacity Metrics Compared

Category	Criteria	Thresholds
Voltage	Overvoltage	≥ 1.051 Vpu at primary node for non-CVR feeders ≥ 1.025 Vpu at primary node for CVR feeders
	Voltage Deviation	≥ 3% change at primary node
Thermal	Section Overload	≥ 100% normal rating

One final subtle difference is that the iterative method uses a time-based power flow solution at each time step while DRIVE uses snapshot power flow and fault-study. Although the power flow solution engines are the same, there may be slight differences in the final solution based on solution convergence and controls. The main implication here is that the final voltage profile and impedances of a feeder might be different which could lead to slightly different hosting capacity results.[23]

2.3 Detailed technical results

The schematics of the five feeders compared are shown in Figure 8. These are all 12 kV feeders with varying load levels, topology, and length as defined in Table 10.

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[22] SDG&E uses separate calculations to meet the ICA requirements for protection-based results

[23] This phenomenon was also observed when comparing the Iterative implementation using different platforms (CYME/Synergi) per the Demo A/B reports published previously [Demonstration Projects A&B Final Reports of San Diego Gas & Electric Company (U 902-E), December 22, 2016]

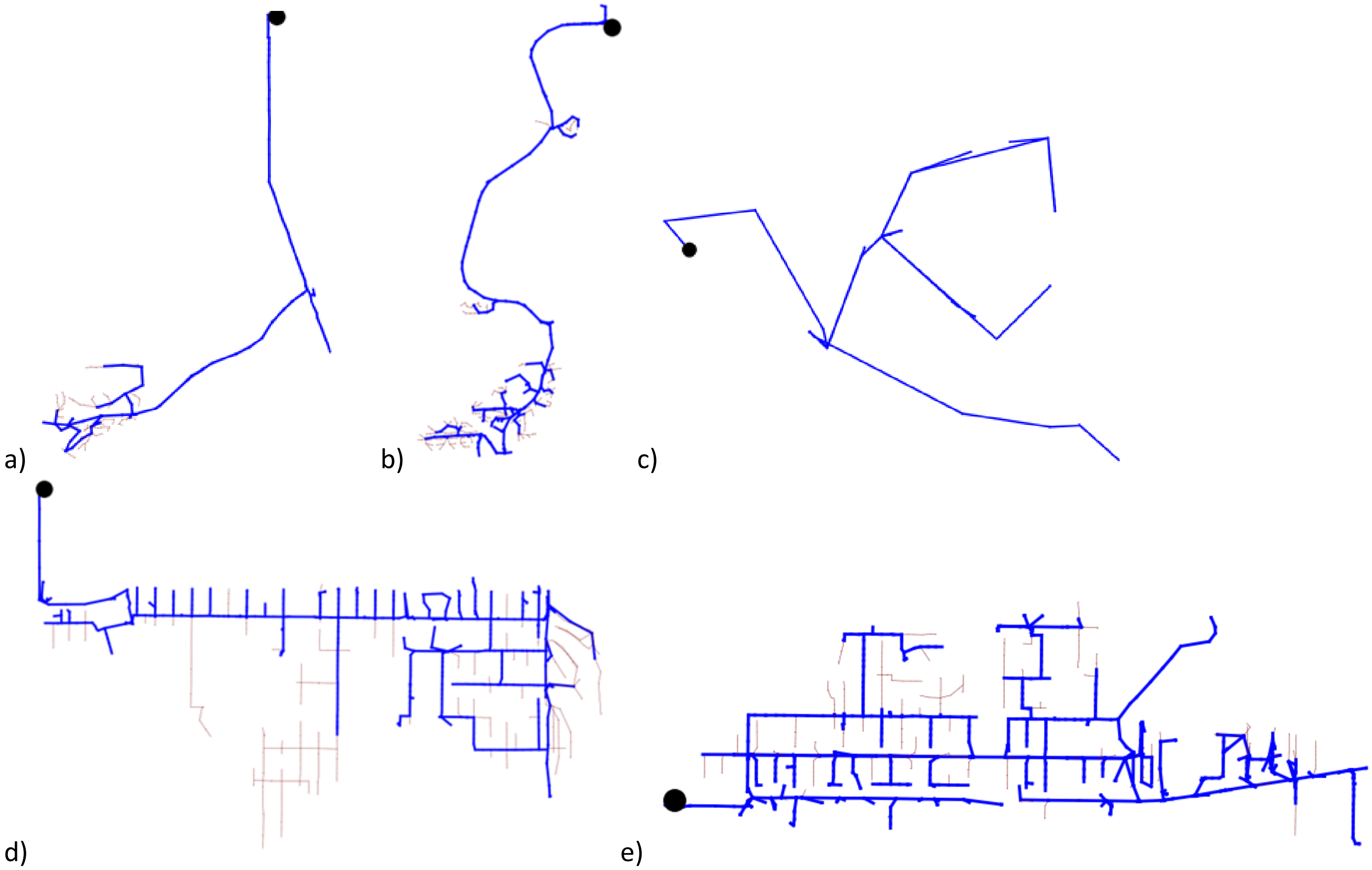

Figure 8. Feeders for Comparison a) A1 b) A2 c) B1 d) C1 e) C2

Table 10. Feeder Characteristics

Feeder	A1	A2	B1	C1	C2
Peak Hour Load (kW)	4360	7962	6441	10335	12336
Min Hour Load (kW)	294	234	3912	4330	4049
January Peak Day 1am Load (kW)	1783	2857	5369	5851	6058
DER (kW)	714	1997	0	861	985
Voltage Class (kV)	12	12	12	12	12
Furthest Point (ft)	27747	41532	4970	20700	16590
Furthest Electrical Distance (ohm)	3.46	1.86	0.50	2.34	1.38
Substation LTC	1	1	1	1	1
Switchable Substation Capacitors	2	2	1	1	1
Line Regulators	0	0	0	0	0
Switchable Line Capacitors	2	2	0	1	1

2.3.1 Single-Hour Comparison

The specific time period comparison uses the first time interval of the 576 point iterative analysis. This time interval simulates 1am of the peak load day in January. This hour was chosen for multiple reasons:

1) All control elements initialize during this hour (compared to hour 2 where control settings depend on the final control state of hour 1 after all DER hosting capacity metrics/locations are analyzed)

2) Existing DER output is zero during this hour (DER is primarily PV). Recall the differences previously noted regarding the application of existing DER in the iterative and DRIVE analyses

The iterative analysis is conducted for the January peak day to determine the 1am control settings. Those settings are then manually applied to create the January 1am peak load snapshot model. Due to differences in the time series power flow and the snapshot power flow algorithms in Synergi previously mentioned, the snapshot models are further refined to achieve a similar power flow solution. Once the power flow solutions matched, the DRIVE hosting capacity analysis is performed. The results from both methods are then compared.

2.3.1.1 Thermal Hosting Capacity

Overall, both methodologies produce similar thermal hosting capacity results as shown in Figure 9. However, there are some inconsistencies. Although results are sorted by descending DRIVE values, this should not imply that the iterative values are incorrect, but rather further examination is required.

Results on Feeders A1 and A2 indicate the inconsistency occurs in the iterative analysis when the section/node under consideration only serves a downstream capacitor. The inconsistencies on Feeders C1 and C2 occur in the iterative analysis when a fuse is located on the outward node of the section whose hosting capacity is being calculated. Further investigation regarding if alternative methods are used in the iterative method, should be considered. The iterative analysis is under further refinement at this time based on these findings.

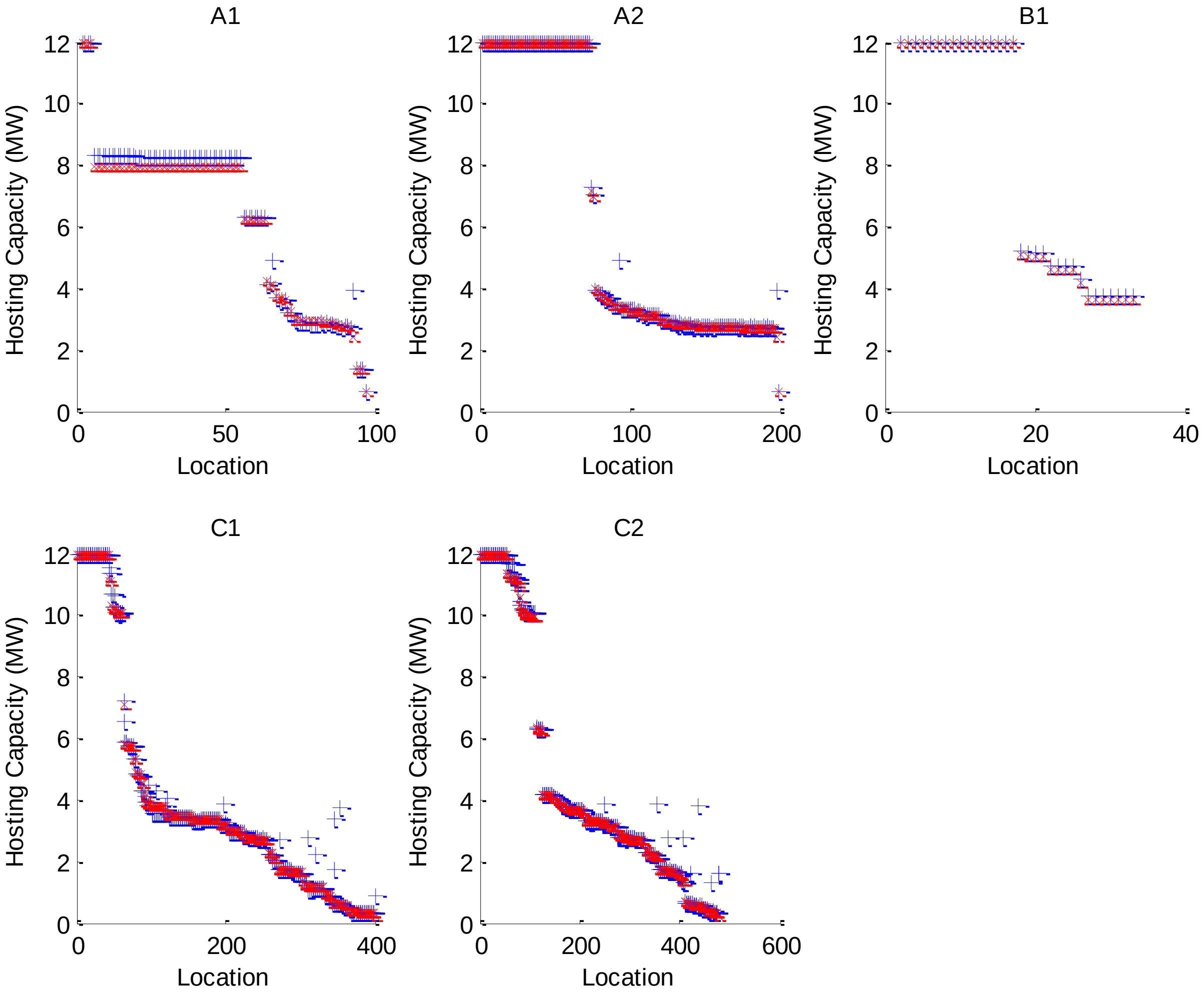

Figure 9. Single-Hour Thermal Hosting Capacity Comparison (Blue +: Iterative Analysis, Red x: DRIVE Analysis)

2.3.1.2 Overvoltage Hosting Capacity

The overvoltage hosting capacity comparison shown in Figure 10 is similar for all feeders except B1 and C2. The inconsistencies for Feeder B1 will be further explained in the next section on voltage deviation hosting capacity. Feeder C2 has a unique feature in that it contains long parallel branches within the feeder. The method by which DRIVE currently conducts the analysis does not consider the impacts that long parallel branches can provide when determining DER hosting capacity at a specific node. For efficiency reasons, the DRIVE analysis assumes that at minimum load, the voltage drop along any branch (short or long) will be minimal, even with long parallel branches. However, when not considering minimum load, as for this specific hour, and when the branches are long and the voltage drop along any particular branch is more significant, the DRIVE results match that of the lower hosting capacity branch (indicated by the DRIVE points matching the lower region of the iterative points). To consider a feeder and scenario with non-minimum load and long parallel branches, DRIVE has been updated and the new results provide a closer match as shown in Figure 11.

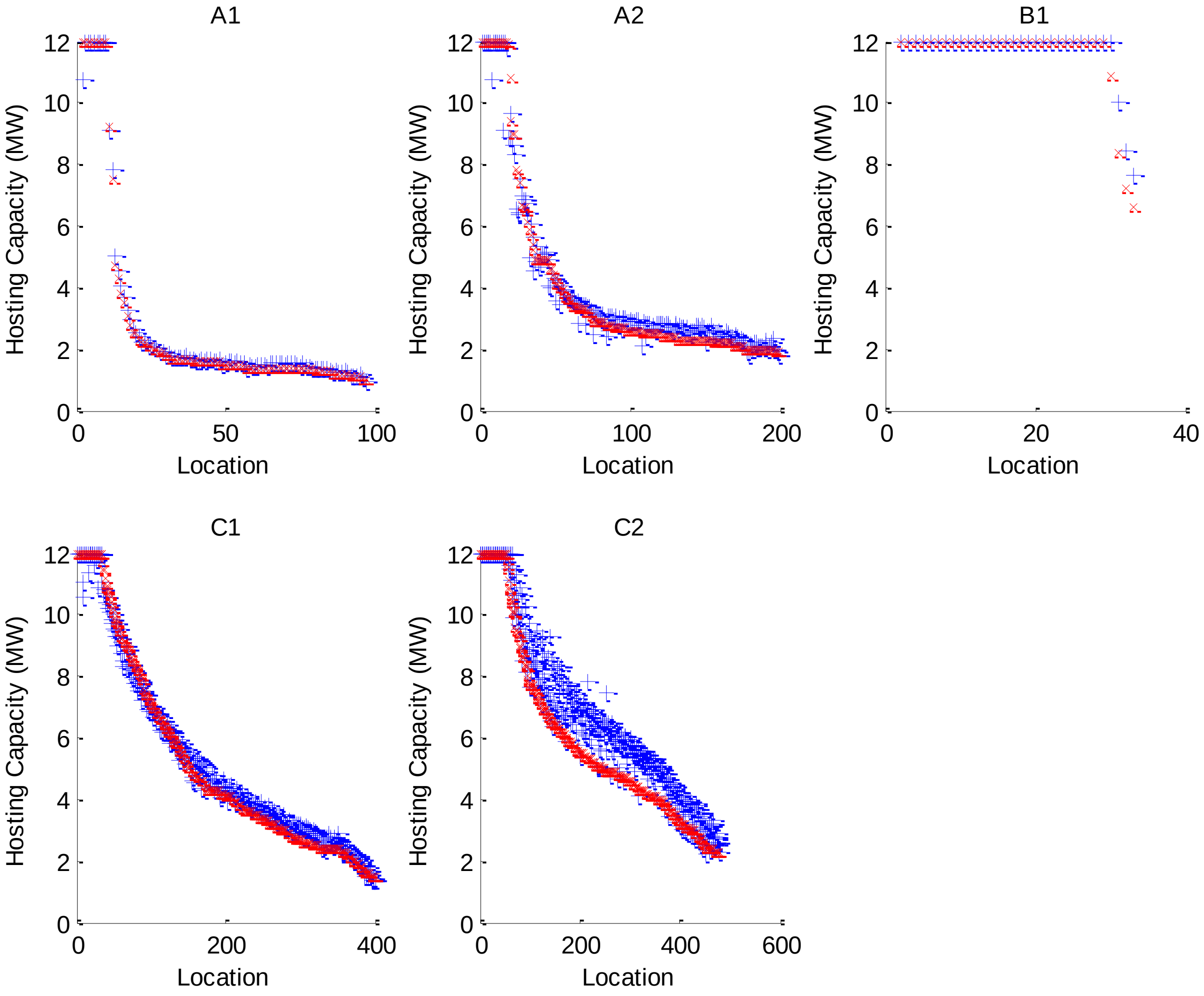

Figure 10. Single-Hour Overvoltage Hosting Capacity Comparison (Blue +: Iterative Analysis, Red x: DRIVE Analysis)

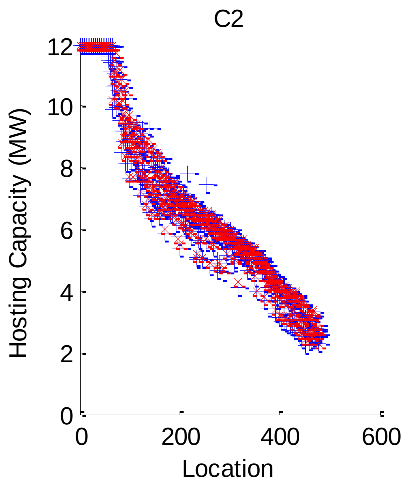

Figure 11. Single-Hour Overvoltage Hosting Capacity Comparison after DRIVE Analysis Overvoltage Algorithm Update. (Blue +: Iterative Analysis, Red x: DRIVE Analysis)

2.3.1.3 Voltage Deviation Hosting Capacity

As shown in

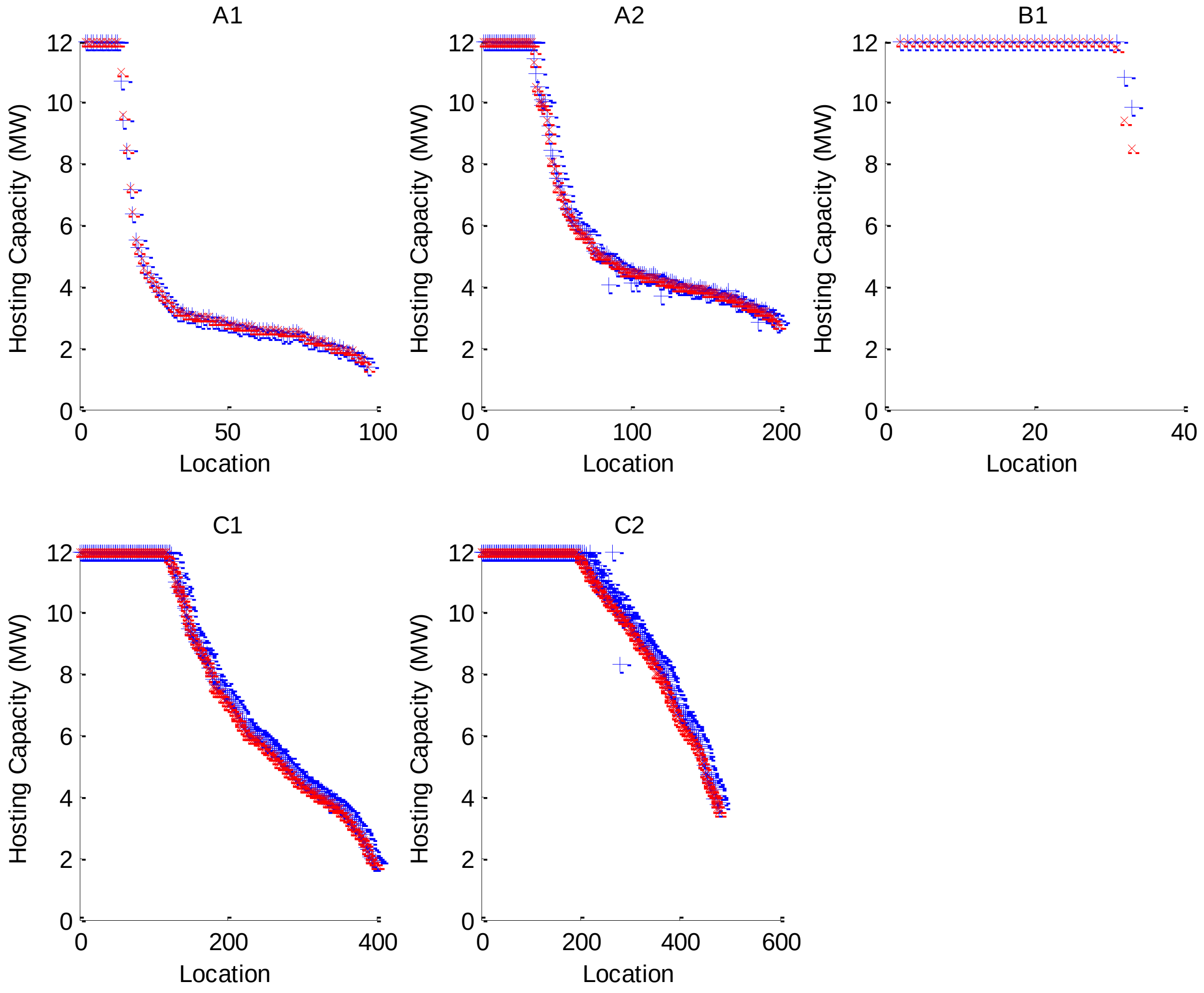

Figure 12, the voltage deviation hosting capacity comparison is very similar besides several inconsistencies for feeders A2, B1, and C2. The inconsistencies on feeder B1 are due to differences in the distribution system impedances used in the analysis. DRIVE uses Thevenin impedances derived from a short-circuit analysis, while the iterative analysis uses the phase impedances from the power flow. Although these values are typically similar, the Thevenin impedances are derived without loads, generators, and capacitors, while the power flow impedances account for the presence of these shunt devices. The difference in impedances also further explains the feeder B1 mismatch for overvoltage hosting capacity. The impact of the impedance used in the DRIVE analysis is under further investigation.

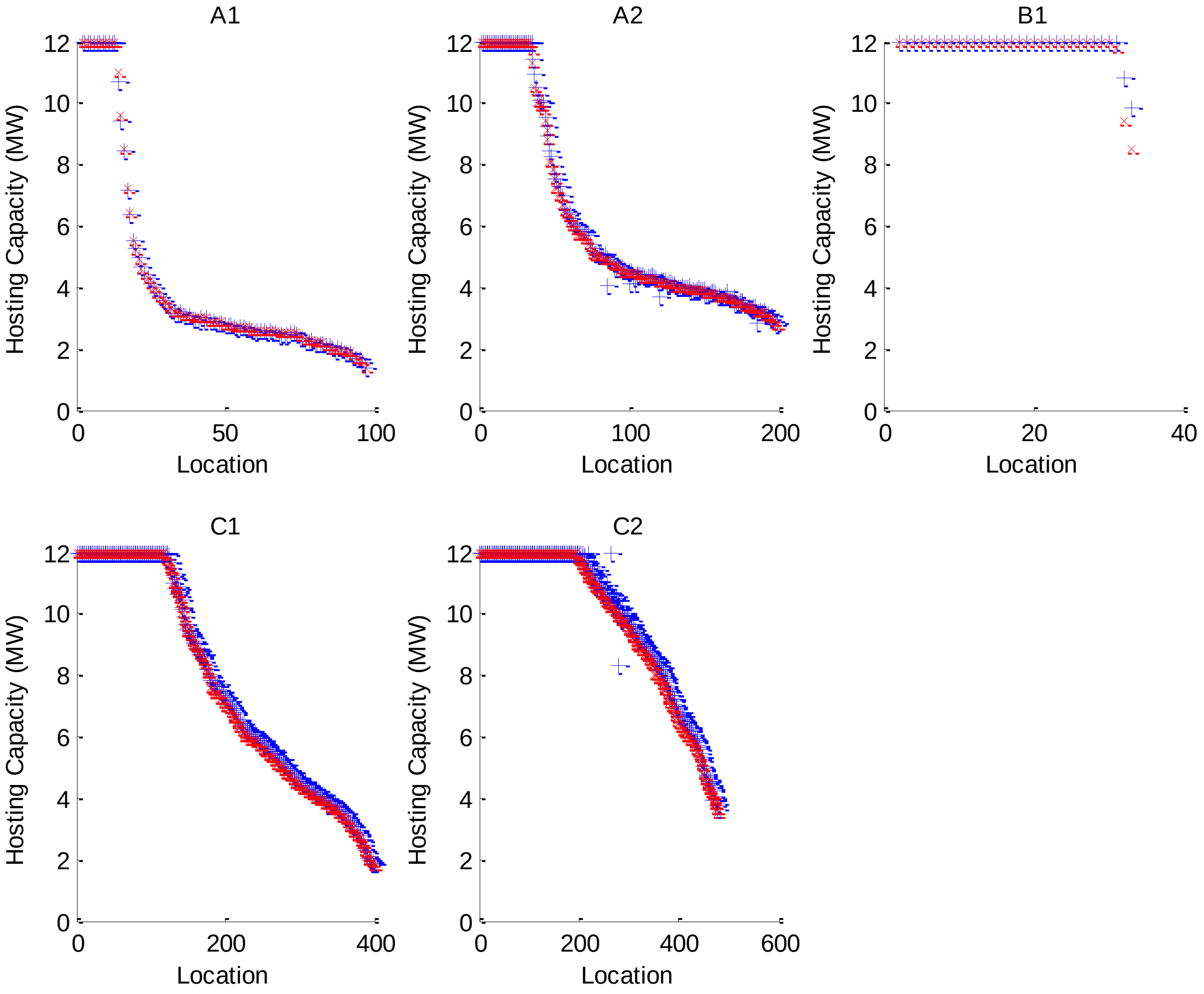

Figure 12. Single-Hour Voltage Deviation Hosting Capacity Comparison (Blue +: Iterative Analysis, Red x: DRIVE Analysis)

The results indicate that the iterative analysis outliers on Feeders A2 and C2 are an error based on the impedance to those locations. More specifically, the single iterative values shown that are significantly less than DRIVE on Feeders A2 and C2 occur at locations that should have a higher hosting capacity. This is illustrated in Figure 13 for the occurrence on Feeder C2. Note that higher impedances should result in lower voltage deviation hosting capacities. Similarly, the single iterative value shown that is significantly more than DRIVE on Feeder C2 occurs at a location that should have a lower hosting capacity. Further investigation should be considered to resolve these inconsistencies.

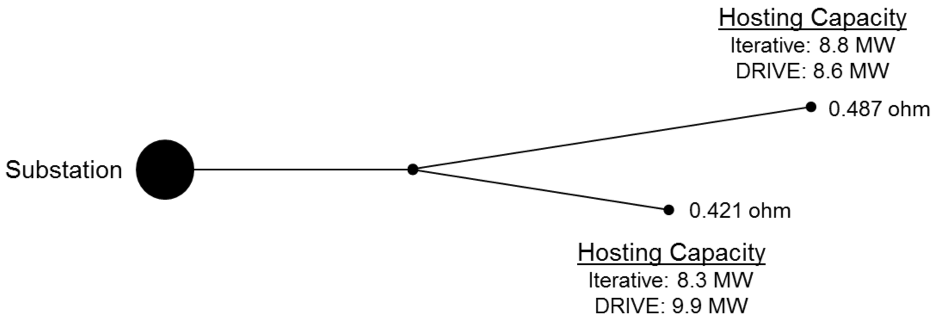

Figure 13. Illustration of Error in Iterative Hosting capacity result

2.3.2 Annual Comparison

The annual comparison goes beyond the specific hour analysis and compares the overall result of each method's full hosting capacity analysis. This will take all the results from the 576 point iterative analysis, find the minimum hosting capacity for each location, and compare those results to the DRIVE analysis conducted on two load conditions. For the DRIVE analysis, the additional level of scrutiny placed on matching the input power flow models is not applied. Rather, the DRIVE analysis scales the base model to the peak and minimum load levels. All existing DER is considered in the DRIVE analysis because peak and minimum load occur during daylight hours, during which time the iterative analysis would also have the DER resource online.

2.3.2.1 Thermal Hosting Capacity

The minimum thermal hosting capacities for each location are similar as shown in Figure 14 except for the discrepancies previously discussed that require further investigation (locations that have 100% reactive power loads downstream or locations with fuses on section's outward node). The overall similarity in results is expected based on the fact that the minimum load hour is analyzed in each methodology, and the minimum load hour sets the minimum thermal hosting capacity in each method.

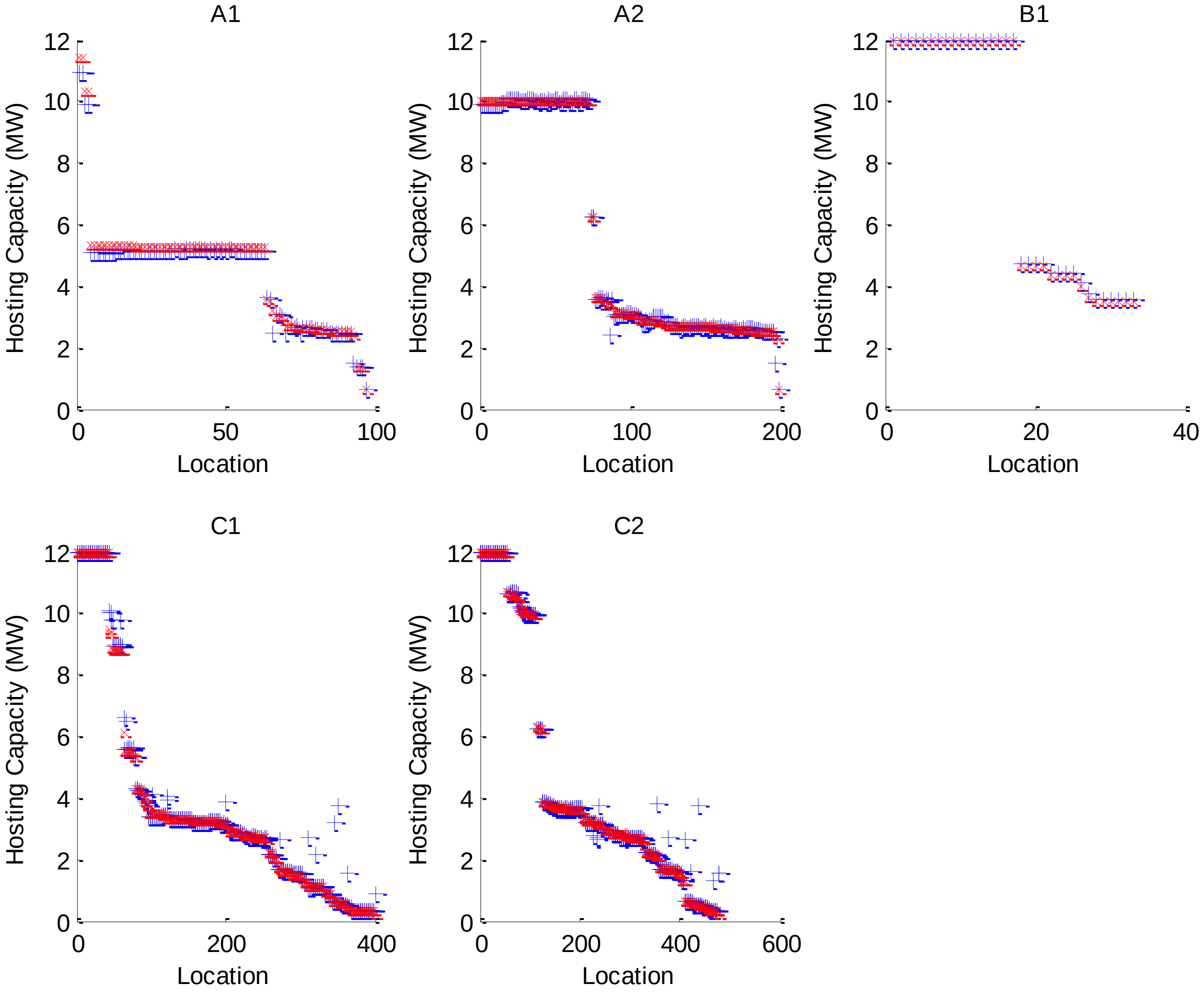

Figure 14. Annual Thermal Hosting Capacity Comparison (Blue +: Iterative Analysis, Red x: DRIVE Analysis)

2.3.2.2 Overvoltage Hosting Capacity

All four feeders with existing DER (A1, A2, C1, C2) showed voltage violations occurred in both the DRIVE and iterative analyses. Based on the DRIVE methodology, each of these four feeders cannot accommodate additional DER at any location until the voltage violation is mitigated. In the iterative methodology, however, three of the feeders with existing DER showed that some (not all) locations could still accommodate DER. These results indicate that the iterative methodology allows additional DER to mitigate the voltage violation and thus allows additional hosting capacity at some locations on the feeder. Currently, the iterative method is under further refinement to deal with pre-existing violations. Further investigation is needed before comparisons can be made.

The one feeder with no existing DER, Feeder B1, shows a significant mismatch in overvoltage hosting capacity as shown in Figure 15. Results indicate this mismatch is primarily due to intentional differences in the overvoltage methodology. Both methodologies use Synergi to run the baseline power flow, thus the voltage profiles used in both are valid for each hosting capacity analysis. However, DRIVE is based upon the premise that hosting capacity is defined as the amount of DER that can be accommodated without adversely affecting power quality or reliability under existing control configurations. As such, using existing voltage regulation to increase hosting capacity is considered a potential mitigation solution. Therefore, the DRIVE results indicate there exists a condition in which the feeder could experience overvoltage at a lower hosting capacity than found in the iterative analysis. Further analysis comparing results to a full quasi-static time series analysis would shed light on this inconsistency.

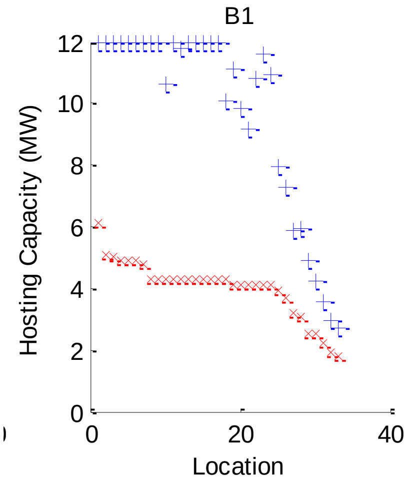

Figure 15. Annual Overvoltage Hosting Capacity Comparison (Blue +: Iterative Analysis, Red x: DRIVE Analysis)

2.3.2.3 Voltage Deviation Hosting Capacity

The voltage deviation hosting capacities between the iterative method and DRIVE analyses match relatively well for Feeders A1 and A2 as shown in Figure 16. The mismatch on Feeder B1 is again due to differences in the impedances used in each analysis. The most significant difference in results occurs on the highest loaded feeders (C1 and C2). The inconsistency is due to the way losses are incorporated in the analyses. Figure 17 illustrates how the comparison improves when the impact of losses is ignored in the DRIVE hosting capacity calculation. Results indicate that the DRIVE calculation to include the impact from losses may need further review, however, these feeders do have relatively high load (refer to Table 10) which typically correlates to higher loss impact. If DER output occurs at peak load, distribution feeder losses decrease, which increases feeder voltage further. Results therefore also indicate losses have insignificant impact in the iterative analysis which should be reviewed.

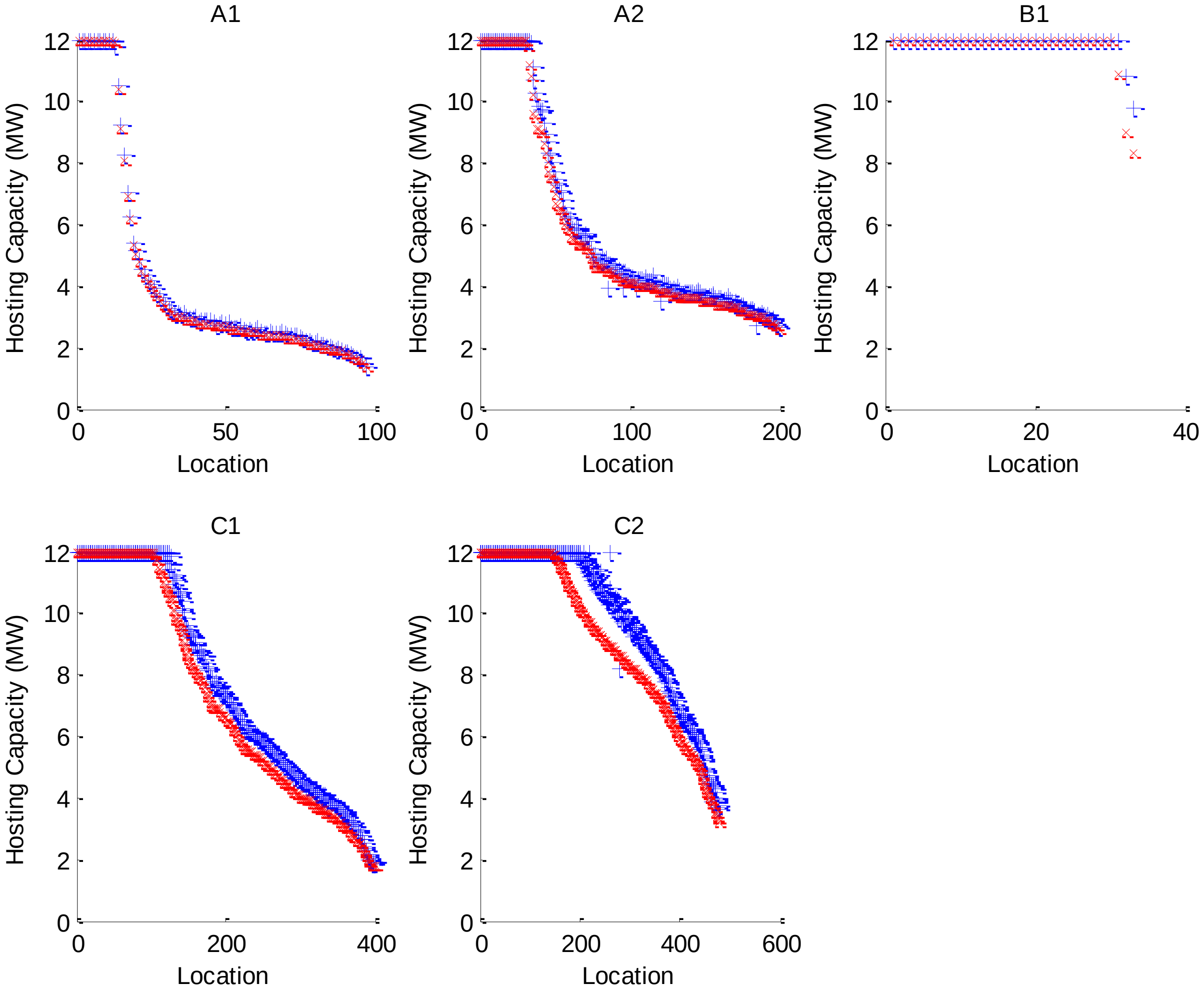

Figure 16. Annual Voltage Deviation Hosting Capacity Comparison (Blue +: Iterative Analysis, Red x: DRIVE Analysis)

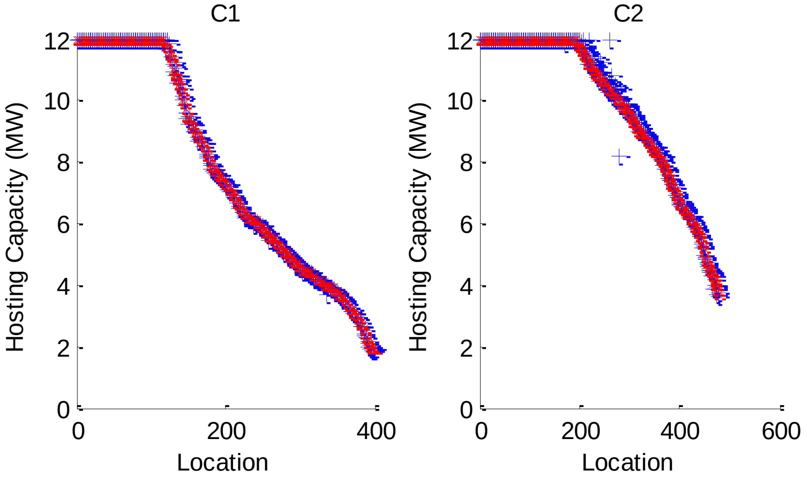

Figure 17. Annual Voltage Deviation Hosting Capacity Comparison when Ignoring the Impact of Losses in DRIVE (Blue +: Iterative Analysis, Red x: DRIVE Analysis)

Results show that the iterative method's voltage deviation hosting capacity values are relatively unchanged for all feeders between the specific-hour analysis and the annual analysis as shown in Figure 18. These results also indicate that the iterative method's voltage deviation hosting capacity is mostly independent of load and losses. Both methods require further investigation.

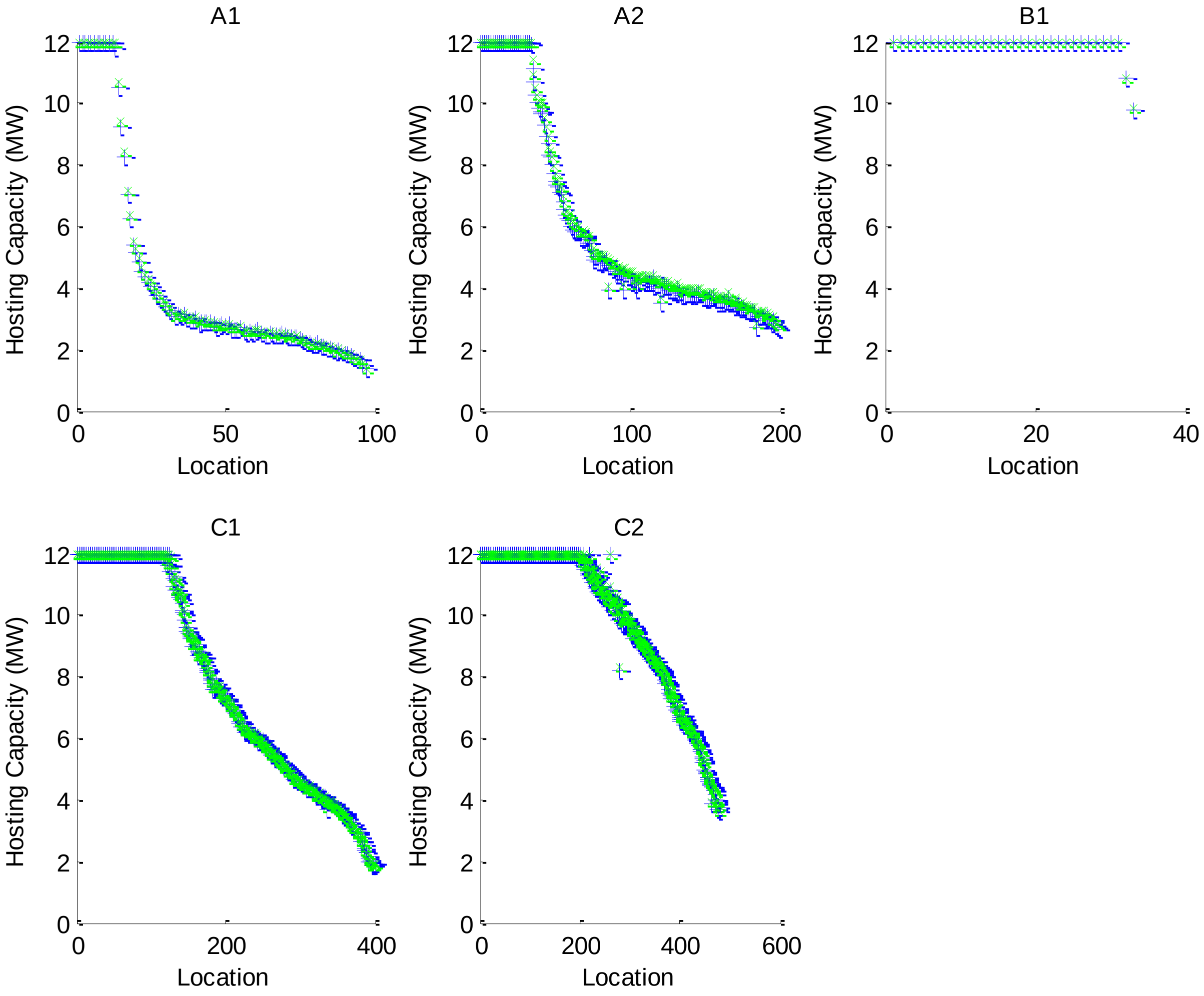

Figure 18. Iterative Voltage Deviation Hosting Capacity Comparison (Blue +: Annual Analysis, Green x: Single-Hour Analysis)

An additional variation in the two hosting capacity methods is that the iterative method does not consider the impact of existing DER on voltage deviation hosting capacity. DRIVE can consider this impact, and when it does, the remaining hosting capacity at each node would reduce from that shown in Figure 16 to that shown in Figure 19. In this case, the total change in voltage due to DER is underestimated in the iterative approach, thus overestimating hosting capacity for Feeders A1, A2, C1, and C2. Note Feeder B1 does not have any existing DER.

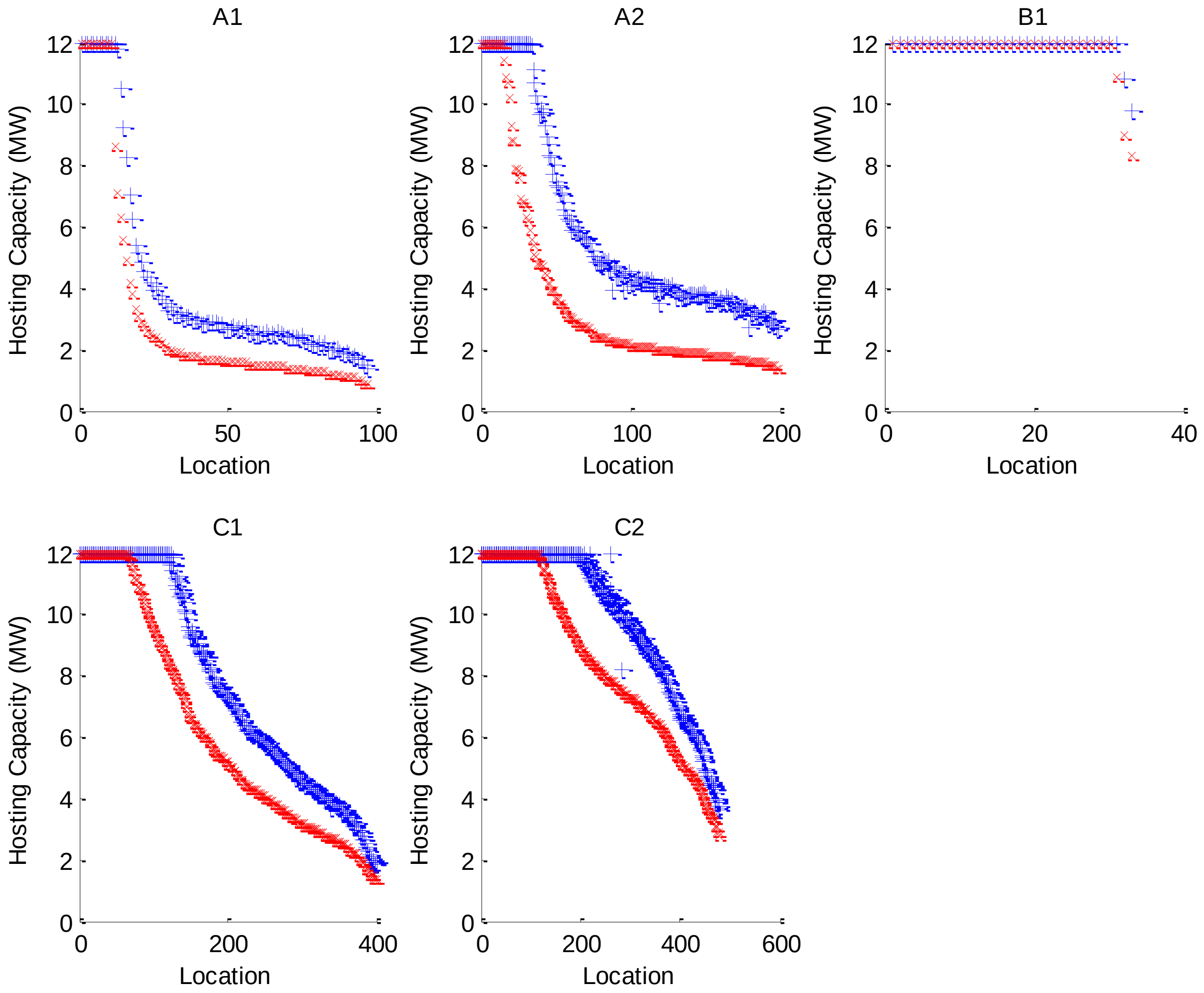

Figure 19. Annual Voltage Deviation Hosting Capacity Comparison with DRIVE Considering Aggregate Impact of Existing DER (Blue +: Iterative Analysis, Red x: DRIVE Analysis)

2.3.2.4 Annual Analysis Summary

Table 11**Error! Reference source not found.** summarizes the minimum hosting capacity value across all nodes from the previous annual analysis figures. Only the initial results are used and not the sensitivities discussed. Without knowing specific feeder location, the minimum hosting capacity values portray the greatest constraint on each feeder for each issue. Although DRIVE did not analyze the load for all 576 time intervals, the hosting capacities are almost identical except for Feeder B1, whose discrepancies were previously explained as a difference in simulated feeder impedance.

Table 11. Annual Hosting Capacity Analysis Summary for All Analyzed Feeders and Nodes

	Iterative ICA (MW)			**DRIVE (MW)**			**Difference (Iterative-DRIVE, MW)**		
Feeder	**Thermal**	**OV**	**Vdev**	**Thermal**	**OV**	**Vdev**	**Thermal**	**OV**	**Vdev**
A1	0.6	0.0	1.4	0.6	0	1.4	0.0	0.0	0.0
A2	0.6	0.0	2.6	0.6	0	2.6	0.0	0.0	0.0
B1	3.6	2.7	9.8	3.5	1.8	8.3	0.1	0.9	1.5
C1	0.3	0.0	1.8	0.2	0	1.8	0.1	0.0	0.0
C2	0.3	0.0	3.6	0.2	0	3.2	0.1	0.0	0.4

2.4 Applying the results

The results of this demonstration project point to opportunities in the future enhancement of hosting capacity analysis methods. These opportunities include the improvement of the underlying methods and the applicability of the results produced from those methods.

3.0 Findings and Conclusions

3.1 Was the project objective accomplished?

The objective of this activity was to perform a demonstration of the DRIVE tool for determining the hosting capacity of distribution feeders for DER. This objective was successfully accomplished on five SDG&E feeders with a range of designs and characteristics.

3.2 Description of measurement and verification results

The demonstration of the DRIVE tool provides insight to the hosting capacity on five SDG&E feeders when considering voltage and thermal impacts. Those results are useful in identifying existing barriers for adoption of DER. The results also provide information to customers and developers to enable more informed decisions on where to submit DER applications. By basing these decisions on hosting capacity information, there is an opportunity to reduce interconnection costs and reach the full hosting capacity potential on feeders.

The outcome of the demonstration points to a consistency in the results of two hosting capacity methods. As shown in Table 12, and discussed in the previous section, the results of the DRIVE demonstration align very closely to the results of the iterative analysis. This comparison, similar to the one done as part of the CA DRP Demos, provides a relative comparison to a third approach.

Table 12. Differences in Annual Hosting Capacity Analysis for All Analyzed Feeder Nodes

	Difference (Iterative-DRIVE)		
Feeder	**Thermal (MW)**	**Overvoltage (MW)**	**Voltage Deviation (MW)**
C1	0.1	0.0	0.0
C2	0.1	0.0	0.4
B1	0.1	0.9	1.5
A1	0.0	0.0	0.0
A2	0.0	0.0	0.0

The comparative analysis also points to differences and areas that require continued improvement in both approaches as well as areas for further investigation as described in Table 13. There are aspects of both analyses that may be unclear to the user. All users and stakeholders should acknowledge these aspects, and the internal functionality that drives them.

Table 13. Areas on Improvement/Understanding in Hosting Capacity Methodologies

Iterative	**DRIVE**
Further examination of inconsistencies in thermal analysis	Further examination of impedances used in voltage analysis
Consider including locking regulation equipment in voltage analysis	Incorporate branch analysis in voltage analysis
Further examination of inconsistencies in voltage deviation analysis	Further examination of impact of losses in voltage deviation analysis
Further examination of applied pre-existing violations	Consider inclusion of adjacent feeders at substation

3.3 Conclusion

This project demonstrates the use of the DRIVE tool for doing hosting capacity assessments on five selected SDG&E feeders. The results found both opportunities for implementation and challenges that require further investigation. While DRIVE has been adopted across the industry with more than 25 utilities worldwide, further refinements/enhancements to both DRIVE and the iterative methodology will continue to be made based on utility applications and demonstrations like that performed here.

Currently, the Iterative ICA analysis is based on the specific requirements within California. However, locking into one method without exploring alternative approaches will ultimately limit innovation in the future. Given this, it is recommended that alternative methods for determining hosting capacity should be considered. Alternative methods have been shown to produce similar results, though it should be noted that more work needs to be done to compare these results to detailed assessments. Alternative methods, based on the efficiencies they provide, would open the analysis to the exploration of impact factors and bring further accuracy to the results. Additionally, alternative methods may be needed as the system becomes more complex – smart inverter technologies, operational flexibility, etc.

What follows is a brief summary of findings, recommendations, and next steps based upon this effort.

3.3.1 Findings

1. **Different hosting capacity methods can provide similar results**
   As detailed in the findings, this project has shown that hosting capacity results of the iterative method are in line with results of the DRIVE hosting capacity analysis. While there were some minor variations noted, these inconsistencies have identified required improvements to one or both methodologies. Based on these results, there are opportunities for the industry to continue to refine and enhance multiple hosting capacity approaches while still achieving consistent results. Specifically, this finding indicates that utilizing DRIVE for SDG&E's ICA could be done with limited impact to results.
2. **Similar hosting capacity results can be derived more efficiently**
   The analysis has shown that the hosting capacity analysis can be performed in a fraction of the time without compromising accuracy of the results. This presents an opportunity for utilities to reduce computational burden and manpower needed to perform hosting capacity analysis. It is an important consideration as utilities are faced with decisions about frequency of the calculations, increased complexity of scenarios (e.g., operational flexibility, smart inverter controls, etc.), and the impact on different hosting capacity applications. Specifically, this finding indicates that SDG&E could save time and resources while achieving a similar result.
3. **Hosting capacity methods will continue to evolve and improve**
   As demonstrated throughout this effort, hosting capacity methods will continue to evolve. As noted, both methods are undergoing updates to improve precision. Likewise, both methods are undergoing further modifications to streamline the underlying algorithms and analysis approaches. While the industry has tried to draw a distinct line between "iterative" and "streamlined" approaches, in the future this will be irrelevant as there will likely be little means of distinction between the two.

3.3.2 Recommendations

1. **SDG&E should keep DRIVE available as one of the tools it can use in future hosting capacity analyses**
2. **SDG&E should monitor the future advances in DRIVE and the emergence of other tools, to be able to make the best choices for specific future assessment needs**
3. **Consider improvements to ICA requirements by reducing hours simulated**
   The results of this project also provided insight into potential opportunities to improve upon the required analysis approach of analyzing all 576 hourly load points per section. This project shows that similar results can be captured without analyzing all 576 hourly load points. It is recommended that further consideration be given

to reducing the number of hours simulated. It ensures a more cost-effective process and enables a more sustainable analysis approach for future complexity.

4. **Consider all potential DER locations in hosting capacity analyses**
   DER location is one of the primary factors impacting hosting capacity (more so than hourly changes in load[24]). As such, all possible DER locations should be evaluated. As noted in the results, only portions of the circuit locations were considered (two-phase and single-phase locations were excluded).
5. **Consider the aggregate impacts of all DER in hosting capacity analyses**
   At present, the current ICA does not consider the impact of existing DER on voltage deviation. Existing DER can contribute to voltage variations for intermittent resources and therefore should be considered in the analysis (currently existing DER is only considered for thermal and overvoltage analysis).
6. **Evaluate the use of regulation equipment for establishing baseline hosting capacity**
   The current ICA method calls for all regulation equipment to operate and therefore mitigate voltage rise from DER. Existing voltage regulation equipment can in some cases be used to mitigate voltage rise and increase hosting capacity, but at the same time, overregulation can lead to potential under-voltages and decreased hosting capacity. These impacts are examined by observing overvoltage and under-voltage simultaneously in the iterative analysis. DRIVE, however, calculates the DER-induced voltage rise prior to regulation equipment operation by considering all regulation equipment locked during the analysis. Caution is recommended when allowing regulation equipment to mitigate DER-induced voltage rise under high penetration scenarios, more specifically:
   i. Under conditions where regulation equipment is "bucking" to prevent DER-induced voltage rise, a sudden loss of generation due to a grid-related (fault) event or market signal could result in further under-voltage conditions for customers elsewhere on the feeder. These under-voltage conditions are not currently examined.
   ii. DER can operate faster than voltage regulation equipment and therefore cause voltage rise prior to regulation equipment operation. The current ICA method assumes existing regulation equipment can mitigate voltage rise, however different DER types can operate considerably faster than the existing regulation equipment (solar, wind, and storage).
   iii. Under-voltage due to overregulation is not specific to DER as it could also occur from by a sudden drop in load.

   Existing regulation equipment is considered adequate for existing load scenarios on the feeder, but the use of the regulation for DER is reserved as a potential solution to increase hosting capacity above baseline by mitigating DER-induced voltage rise. However, consideration as a mitigation solution warrants careful thought regarding the application and DER type. This can be particularly important as more advanced solutions, such as smart inverters, are deployed.
7. **Calculate the impacts of smaller-size DER within the ICA to prepare for future applications in planning**
   Current ICA analysis does not calculate the hosting capacity of smaller-size DER. However, prior analysis has shown that rooftop PV has a significant impact on hosting capacity results. It is recommended that including smaller-size DER analysis is critical when using hosting capacity for future applications like planning the distribution system.
8. **Perform detailed time-series analysis of DER impacts to compare ICA and DRIVE hosting capacity methods to assess accuracy**
   The comparison analyses performed to date in the industry are assessing the differences in results from one method to another but not assessing the accuracy of either. To evaluate accuracy, it is recommended that comparisons be performed with a detailed, time-series analysis of specific DER locations, technologies, etc. to better understand method accuracies. There is a certain level of implied precision and accuracy using a 576-

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[24] Pacific Gas and Electric Company's (U 39 E) Demonstration Projects A and B Final Reports, December 27, 2016

hour approach that should be further investigated. This is of particular importance if ICA results begin being used more for interconnection assessment approval.

9. **Perform a more rigorous assessment of hosting capacity methods to better understand inconsistencies**
   Based on this initial comparison, it is clear there are benefits to doing a more in-depth comparison of the various hosting capacity methods and input assumptions. As noted, the results point to several items driving discrepancies, and it is recommended that the following be considered:
   - The use of voltage regulation equipment in mitigating voltage rise. As noted, the current ICA method calls for regulation equipment to operate and mitigate DER-induced voltage rise wherein DRIVE calculates the voltage rise prior to regulation operation.
   - Pre-existing conditions. As noted, the two approaches appear to handle pre-existing conditions (feeder violations prior to the hosting capacity calculation) differently and further investigation is needed to determine when and how this affects results.
   - Alternative methods for determining DER hosting capacity should be investigated.
   - Determine when model inconsistencies (such as inclusion of adjacent feeders on the substation, branches on the feeder under study, and variance in electrical characteristics) can significantly impact the hosting capacity results.
10. **Perform sensitivity analysis on DER and grid impact factors to improve accuracy**
    An important point frequently overlooked in discussions of hosting capacity methods is that the impact factors, not methods themselves, are the main driver to improve accuracy of results. Knowledge of these impact factors led to the consistency of analysis defined in section 2.2. There is an opportunity for the industry to better understand these impact factors and how they affect hosting capacity results. It is recommended that a sensitivity analysis be performed to understand the extent to which these drive accuracy, which in turn can inform what is most critical for analysis.
11. **Perform a protection impact assessment comparison**
    The iterative fault flow protection-based hosting capacity assessments are often significantly more time consuming and computationally difficult to perform. It is recommended that a similar assessment to that done in this project for power flow hosting capacity issues be performed for iterative protection-based methods.

4.0 Technology Transfer Plan

A primary benefit of the EPIC program is the technology and knowledge sharing that occurs both internally within SDG&E and across the industry. To facilitate this knowledge sharing, SDG&E will share the results of this project by widely announcing the availability of this report to industry stakeholders on its EPIC website, by submitting papers to technical journals and conferences, and by presentations in EPIC and other industry workshops and forums. Additionally, presentations will be given to internal stakeholders at SDG&E.

5.0 Metrics and Value Proposition

5.1 Metrics

The following metrics (discussed in Table 14) were identified for this project as potential project benefits at larger scale deployment. Given the pre-commercial nature of this EPIC project, these metrics would apply in future scenarios after widespread commercial adoption. The following metrics are potential benefits that are concluded from different tests cases performed in this effort:

Table 14. EPIC metrics for pre-commercial demonstration of EPRI DRIVE DER hosting capacity tool

D.13-11-025, Attachment 4. List of Proposed Metrics and Potential Areas of Measurement (as applicable to a specific project or investment area in applied research, technology demonstration, and market facilitation)
1. Potential energy and cost savings
b. Total electricity deliveries from grid-connected distributed generation facilities
e. Peak load reduction (MW) from summer and winter programs
f. Avoided customer energy use (kWh saved)
i. Nameplate capacity (MW) of grid-connected energy storage
3. Economic benefits
b. Maintain/reduce capital costs
c. Reduction in electrical losses in the transmission and distribution system
4. Environmental benefits
a. GHG emissions reductions (MMTCO2e)
5. safety, power quality, and reliability (equipment, electricity system)
b. electric system power flow congestion reduction
7. Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy
d. Deployment and integration of cost-effective distributed resources and generation, including renewable resources (PU Code § 8360)

5.2 Value Proposition

The purpose of EPIC funding is to support investments in R&D projects that benefit the electricity customers of California IOUs. The primary principles of EPIC are to invest in technologies and approaches that promote greater reliability, lower costs, and increased safety. Table 15 represents the value that "pre-commercial demonstration of EPRI DRIVE DER hosting capacity" project provides to the overall system operation. Primary and secondary benefits are presented wherever applicable to demonstrate the value of the function for commercial adoptability.

Table 15. Value proposition (primary and secondary) for pre-commercial demonstration of EPRI DRIVE DER hosting capacity tool

Primary Principals			Secondary Principals					
Reliability	Affordability	Safety	Societal Benefits	GHG Emissions Mitigation / Adaptation	Loading Order	Low-Emission Vehicles / Transportation	Economic Development	Efficient Use of Ratepayers Monies
X				X				X

As it is shown in Table 15 and was discussed in the result and conclusion section of this report, pre-commercial demonstration of EPRI DRIVE DER hosting capacity primarily can enhance systems reliability by optimal DER placing and sizing. Furthermore, it can contribute to GHG emission reduction by finding and suggesting optimum number, size, and location of DER in a distribution system. These principles can eventually lead to efficient use of ratepayers’ monies.