414 Nicollet Mall
Minneapolis, MN 55401

February 28, 2018

—Via Electronic Filing—

Daniel P. Wolf
Executive Secretary
Minnesota Public Utilities Commission
121 7th Place East, Suite 350
St. Paul, MN 55101

RE: REPLY COMMENTS
2017 HOSTING CAPACITY REPORT
DOCKET NO. E002/M-17-777

Dear Mr. Wolf:

Northern States Power Company, doing business as Xcel Energy, submits the enclosed Reply Comments in response to the parties who submitted comments on February 2, 2018 in the above-referenced docket.

Pursuant to Minn. Stat. §216.17, subd. 3, we have electronically filed this document with the Minnesota Public Utilities Commission, and copies have been served on all parties on the attached service list. Please contact Jody Londo at jody.l.londo@xcelenergy.com or (612) 330-5601 if you have any questions regarding this filing.

Sincerely,

/s/

BRIA E. SHEA
DIRECTOR, REGULATORY & STRATEGIC ANALYSIS

Enclosures
c: Service Lists

STATE OF MINNESOTA
BEFORE THE
MINNESOTA PUBLIC UTILITIES COMMISSION

Nancy Lange	Chair
Dan Lipschultz	Commissioner
Matthew Schuerger	Commissioner
Katie J. Sieben	Commissioner
John A. Tuma	Commissioner

IN THE MATTER OF THE XCEL ENERGY 2017 HOSTING CAPACITY REPORT UNDER MINN. STAT. § 216B.2425, SUBD. 8

DOCKET NO. E002/M-17-777

REPLY COMMENTS

INTRODUCTION

Northern States Power Company, doing business as Xcel Energy, submits these Reply Comments in response to the parties who submitted comments on February 2, 2018 in the above-referenced docket. We note that these comments are not responsive to the report by Lawrence Berkeley National Labs that was submitted on February 22, 2018. To the extent the Commission finds it would be helpful to the Commission's consideration of our 2017 hosting capacity analysis (HCA), we are open to submitting supplemental reply comments.

We appreciate parties' thoughtful comments, which were generally around the goals of a hosting capacity analysis, underlying assumptions, accuracy of the analysis, and potential improvements for future reports. The comments demonstrate the interrelatedness of several issues and ongoing Commission proceedings, including grid modernization, interconnection processes, and integrated distribution planning.

The Department of Commerce observes a change in the goals that the Commission set-out for the HCA from the first report in 2016 to the present 2017 report – and concludes that our report meets the stated goals. These goals are to: (1) provide a high level understanding of the distribution system's hosting capacity as a starting point for interconnection applications; and (2) serve as a guide for the orderly development and investment in the distribution system to further integrate Distributed Energy Resources (DER).

Parties appear to generally understand that the HCA is evolving, and expressed appreciation for the improvements in our 2017 analysis – including the new heat map view of our hosting capacity results. We agree with parties that our HCA is a work in progress and that there are further improvements to be made. Minnesota has been on the forefront of this issue; however, hosting capacity analysis is becoming more widespread as utilities, regulators, and other stakeholders look for ways to support and evaluate the impacts of growing penetrations of DER. We are committed to monitoring and learning from these changes as these analyses and their linkages with other processes such as interconnection and integrated distribution planning mature.

To this end, in early February the Electric Power Research Institute (EPRI) published its anticipated *Impact Factors, Methods, and Considerations for Calculating and Applying Hosting Capacity, 2018 Technical Update* (EPRI Report), which examines factors that influence hosting capacity results, methods used throughout the industry, and recommendations on method applications.[1] The report outlines important considerations when implementing a hosting capacity analysis for the purpose of informing interconnection, planning, and developers. The report provides helpful, objective analysis of the state of HCA and its trajectory, which we believe will also be informative to questions and issues raised by parties in this proceeding. We provide the report as Attachment A to this Reply, and outline the specific takeaways below:

- Comparison efforts of the various hosting capacity methods thus far have been premature and limited in scope.
- Different methods can provide similar results.
- Mandating how hosting capacity should be calculated sets the industry up for costly risks.
- Hosting capacity analytics will continue to evolve and are already adopting mechanics of each other, making it more difficult to draw clear distinctions between methods.
- Methods are important, but the results are what matter most.
- Hosting capacity results are driven by the impact factors considered.
- A hybrid hosting capacity method is the most likely path forward.

Significant areas of interest, as hosting capacity analyses have gotten underway with various utilities and jurisdictions, is on the different methods employed to achieve the stated goals, the accuracy of those methods, and the purposes for an HCA. This correlates similarly with the issues and questions raised with respect to our HCA. For example, the Interstate Renewable Energy Council, Inc. (IREC) advocates for use of the California iterative method. Both IREC and Fresh Energy suggest the purpose of

[1] https://www.epri.com/#/pages/product/000000003002011009/

the HCA should be to supplant detailed engineering analyses that are presently part of the interconnection application process – and that if our present DRIVE tool is unable to do so, perhaps we should employ a different tool in the future. We believe that engineering studies presently play an important role in the interconnection process that cannot be supplanted by a HCA, and the EPRI Report supports that conclusion. Further, Minnesota's interconnection process is governed by Minn. Stat. § 216B.1611, which requires the Commission to establish statewide generic utility interconnection standards; presently, Xcel Energy is the only utility required to perform a HCA.

The EPRI Report also observes that while HCA goals generally align across the utilities currently employing HCAs, there is no scientific basis for distinction between the methods of producing the HCA.[2] The implication surrounding discussion of the various methods has been that the iterative method is superior – and that there is a natural progression from the other methods to the iterative method. The EPRI Report dispels this notion, and also concludes that the time and intensity of the iterative analysis is not practically scalable from a planning perspective in its present form. The report also dispels the notion that the Iterative ICA method is the same as a detailed study, in that power flow and fault flow analyses are performed for each iteration of DER, and can therefore be used in the place of an interconnection study.

With respect to accuracy, the EPRI Report discusses and concludes that thus far, method comparisons have not actually assessed accuracy. Rather, they have tested precision relative to each other in producing similar results – noting that a method can be precise, and at the same time be inaccurate. As far as methods employed for HCAs, the EPRI Report makes several recommendations:[3]

- *Methodology distinctions are just a label.* There is no clear scientific basis for, or justification and distinction between the methods. Through extensive analysis, EPRI has found that methods are adopting procedures used with other methods.
- *Hosting capacity methods will continue to evolve and improve.* Methods are undergoing modifications to streamline the underlying algorithms and analysis approaches. The industry's attempt to draw a distinct line between "iterative" and "streamlined" approaches will be irrelevant in the future, and there will likely be little means to distinguish between the two.

[2] The EPRI DRIVE Tool that we presently employ is in the hybrid category.
[3] EPRI Report at pages 3-30 to 3-31.

- *Mandating how hosting capacity should be calculated sets the industry up for costly risks.* This risk has been observed already in California where the iterative approach was adopted, but operational flexibility calculations are having to rely on heuristics due to the computational intensity.
- *Comparison efforts thus far have been premature.* While a great deal of work has been done to attempt to compare the methods, many were premature, limited in scope, and were neither comprehensive nor definitive.
- *Different hosting capacity methods can provide similar results.* Working with San Diego Gas & Electric (SDG&E), EPRI has recently demonstrated that DRIVE was found to produce the nearly identical results as found in the California Iterative ICA method.

We are committed to monitoring, learning, and continuing to evolve and improve our HCA as the industry continues to undergo change. Our HCA is meeting the objectives set-out in statute and by the Commission. We acknowledge that our HCA is a work in progress like other leading utilities, and we appreciate the engagement of stakeholders to help inform the industry path as the issue of hosting capacity analysis and related processes mature.

Our Reply Comments are organized as follows:

A. Purpose of the HCA
B. Accuracy of the HCA
C. Potential Improvements to Future HCA Reports
D. Party Questions
E. Procedural Issues

REPLY COMMENTS

A. Purpose of the HCA

The Department of Commerce observes a change in the goals that the Commission set-out for the HCA from the first report in 2016 to the present 2017 report – and concludes that our report meets the stated goals as follows: (1) provide a high level understanding of the distribution system's hosting capacity as a starting point for interconnection applications; and (2) serve as a guide for the orderly development and investment in the distribution system to further integrate DER. We discuss these in turn.

1. Starting Point for the Interconnection Process

As discussed and illustrated in our report, the HCA is a starting point for parties wishing to interconnect DER to our system. With this report, we improved the tools publicly available to include a heat map – and put all of the tools on our website with our other interconnection-related reference materials. We acknowledge that this first heat map tool may be further improved, as noted by parties. However, we disagree that the 2017 HCA should supplant present interconnection steps or studies.

We believe an area of overlap between the Commission's generic inquiry into Minnesota's statewide standards for interconnection and operation of DER and our HCA is emerging, and would benefit from clarification from the Commission in order to avoid potentially conflicting objectives.

Our objective for the HCA is aligned with Minnesota statute toward streamlining interconnections, and the Commission's Order to serve as a starting point for interconnections. The one-size-fits all approach proposed by IREC, to use hosting capacity as the sole tool for technical interconnection processing, is not practical presently – and may not be the best option in the future. IREC has yet to provide evidence from the U.S or other countries to suggest that hosting capacity, used as they describe, is the preferred approach to meet an objective of streamlining interconnections, or one that is relevant to Minnesota. It is also not supported by EPRI's extensive work to understand the state of the industry, which resulted in the EPRI Report that we discuss and provide as part of this Reply.

While the ongoing conversation in California provides one data point for approaching a HCA, many others are exploring and adopting other methods. The EPRI Report observes the various methods being applied across the U.S., including: Stochastic, Iterative, Streamlined, and Hybrid. These methods emerged from the varying intended uses and guidance in various jurisdictions. The below table from the Report demonstrates the present use of these methods – the overwhelming majority of which are using the Hybrid approach:

Table 1: Range in Hosting Capacity Implementations Developed in Recent Years

Method	Industry Adoption	Recommended Use Case
Stochastic	Pepco, ComEd	+Enabling Planning +Informing the public
Iterative	SCE, SDG&E	+Assisting with Interconnection +Informing the public
Streamlined	PG&E	+Enabling Planning +Informing the public
Hybrid – DRIVE	>27 utilities worldwide (including Xcel, NY)	+Enabling Planning +Informing the public +Assisting with Interconnection

Source: EPRI Report, page viii

A driver of California's current Iterative ICA method was to assist with interconnection, as has been the case with utilities using the Hybrid method. EPRI dispels common misperceptions associated with the Iterative method and concludes that it is not a foregone conclusion that the California Iterative ICA method will emerge as a best practice – nor if other state regulatory commissions, utilities, and stakeholders possess the level and type of resources required to enter into an intensive statewide hosting capacity effort to try to replace detailed interconnection studies. EPRI observes that the Iterative method is not scalable and that there is a common misperception that it is the same as a detailed study in power flow and fault flow analyses and can therefore be used in the place of an interconnection study.[4] EPRI also asserts that distinctions in the present form of methods will become irrelevant in the future; the present methods are already adopting mechanics of each other, and as that continues, the approaches will converge.[5]

We believe a HCA plays an important role in streamlining the interconnection process, and we look forward to continuing to refine and advance our HCA in concert with the industry. However, a HCA is only one tool among several necessary to accommodate and integrate DER without causing adverse impacts on the distribution system.

Further, Minn. Stat. § 216B.1611 governs interconnection standards and requires the Commission to establish generic standards for utility tariffs for interconnection of up to 10 MW of interconnected capacity. The Commission has established standardized terms for processing interconnection applications across utilities in the state, and is

[4] Report at 3-11.
[5] Report at xi.

presently re-examining and updating the standards that were established under its September, 28, 2004 Order in Docket No. E999/CI-01-1023.[6]

Screening and studies are core components of the present standardized interconnection processes across Minnesota utilities. Based on our participation in the Distributed Generation Working Group (DGWG) that is working within the Commission's ongoing generic proceeding regarding updates to the statewide interconnection standards, we believe Minnesota will be adopting a modified version of the Federal Energy Regulatory Commission (FERC) Small Generator Interconnection Process (SGIP) as the standardized Minnesota utility process.[7]

The SGIP framework contains two tiers of technical screens for eligible projects[8]: (1) Initial Review, and (2) Supplemental Review. Initial Review screens are first applied, and any failure advances the project to Supplemental Review screening. The SGIP Initial Review screening process is precisely defined in interconnection process rules, and – if adopted without modification, each screen would need to be applied exactly as stated to be in compliance with the uniform statewide process. This precludes the use of a HCA as a means of performing initial review screening.

In anticipating a potential cross-over issue to our HCA proceeding, we proposed language be added to allow the use of alternative initial review screening methods.[9] We intended the language to include a HCA, but also to include a broader set of analytical tools designed to automate interconnection processing. A tenet held by many non-utility stakeholders in the DGWG, including IREC and Fresh Energy, is that all utilities shall use identical initial review technical screens. For this reason, the stakeholders rejected our proposal to include language enabling automation and streamlining of interconnection applications in the way we proposed. Comments by some of the same parties in the present HCA proceeding conflict with those in the DGWG and suggest that we should deviate from a uniform statewide interconnection process and rather use the HCA to automate screening – and perhaps supplant at least some interconnection analyses that are also part of the standardized process.

The record in this docket has primarily considered the topic of hosting capacity without asking what would be the most effective and efficient path to streamlining

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[6] *See* NOTICE OF NEW DOCKET NUMBER, COMMENT PERIOD, AND TECHNICAL CONFERENCE, *In the Matter of Updating the Generic Standards for the Interconnection and Operation of Distributed Generation Facilities Established under Minn. Stat. § 216B.1611*, Docket No. E999/CI-16-521 (June 21, 2016).

[7] See Docket No. E999/CI-16-521, Interconnection and Operation of Distributed Generation Facilities Established Under Minn. Stat. §216B.1611.

[8] Projects that are eligible to enter the Simplified Inverter and Fast Track processes are eligible for screening.

[9] Docket No. E999/CI-16-521, Distributed Generation Working Group (DGWG).

interconnection technical analysis. We contend that the discussion on ultimate hosting capacity objectives must also consider this broader question.[10] As previously mentioned, state statute requires any screening analysis originating from Minnesota interconnection standards be taken up on a statewide basis. Based on this requirement, the entire Minnesota regulated utility landscape must be considered when evaluating paths to streamlining interconnections. We caution stakeholders from proposing a situation where a tool is a solution that is looking for a problem to solve. There is much work already underway to streamline interconnections. We agree that hosting capacity is a valuable part of an interconnection process, and look forward to further discussions on specifically what parts of interconnection streamlining is targeted by hosting capacity in Minnesota for *all* utilities.

2. *Guide for the Orderly Development and Investment in the Distribution System to Further Integrate DER*

Our primary objective for the HCA to-date has been to provide information to the public that helps to guide DER integration and development on the distribution system. The EPRI Report provides substantial discussion about HCA across the U.S. We have found this report to be a helpful tool to aid our understanding of the HCA landscape, which is clearly still evolving. While there seems to be growing interest in utilities utilizing HCA results toward their distribution system planning, it is our understanding that this generally evolutionary and is a longer-term objective. We are one of the few utilities at the forefront of HCA nationally. Improved planning tools and industry advancement resulting from further study and research are needed before this can occur. In the near-term, we expect that we will continue to use our system planning tools to form the HCA – and continue to evolve our HCA to provide increasing value to those who wish to interconnect to our distribution system.

B. Accuracy of the HCA

Accuracy is an important aspect of everything that we do, including our HCA. To this end, we applied learnings from our last HCA to improve our 2017 HCA – and worked to increase the transparency of our analysis for stakeholders. We believe that some of the comments on our HCA project a trajectory that has the HCA not only *aiding* the interconnection process – rather, replacing detailed engineering studies. To this end, some parties suggest that DRIVE may not be the proper tool. Further, IREC specifically suggests that the California iterative method is the most accurate, implies it

[10] The "ultimate objectives" is intended to describe objectives beyond the current analysis being performed which meets legislative mandates.

is the method to which utilities should aspire for their HCA, and points to the iterative method as a way to replace interconnection studies.

As we have noted, we acknowledge that our HCA is a work in progress; we are learning along with other utilities and stakeholders as the industry matures. We believe, however, that our HCA provides a reasonable assessment of hosting capacity to serve as a starting point for the interconnection process. We also agree with the Department that our HCA meets our statutory requirements and the goals the Commission set-out in its Order for our 2017 HCA.

In this section, we discuss the state of the industry with respect to HCA accuracy assessments and the California iterative method as it relates to accuracy and the interconnection process. We also address parties' requests for additional information regarding our assumptions and analysis, and respond to concerns regarding the accuracy of our present HCA and the assessment we conducted on our 2016 HCA results.

1. *State of the Industry – Methods and Accuracy*

The EPRI Report provides helpful insights on the state of the industry – one of which is that the accuracy assessments that have occurred to-date have been premature and not comprehensive. The report also notes that in a study EPRI worked on with SDG&E recently, the California iterative method is not proving to be more accurate than the hybrid method.[11] Further, the report concludes that the HCA results from the California iterative method are *not* a substitute for power flow and other analyses that are part of interconnection studies and processes.

Importantly, EPRI also concludes that mandating *how* hosting capacity should be calculated sets the industry up for costly risks – which it says has already been observed in California. Rather than focus on the underlying algorithms, the focus should be on the HCA results – and performing ongoing comparisons and validation on the evolving methods to ensure the results continue to meet industry expectations. However, the industry has yet to figure out how to do this cost-effectively. We asked EPRI to help forge a path for the industry, and we have since committed to work with EPRI and several other utilities toward cost-effectively assessing the accuracy of our HCA results. We will share the status and results of this effort with the Commission and stakeholders as part of our 2018 HCA filing.

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[11] It is our understanding that EPRI worked with SDG&E on an accuracy analysis of their ICA iterative capacity analysis method that SDG&E is required to make public February 28, 2018.

We are presently meeting our statutory and Commission HCA objectives to aid the interconnection process by using our hybrid DRIVE tool. The EPRI analysis with SDG&E demonstrates that the accuracy of DRIVE is comparable to the iterative method. We are committed to working with EPRI and other utilities to further industry accuracy assessments. There is no basis or reason to change course at this point with our present hybrid DRIVE tool.

2. Certain 2017 Hosting Capacity Analysis Results

Fresh Energy noted certain results in our 2017 HCA, and suggested that perhaps they may be indicative of an error in our analysis. The hosting capacity results for the three feeders mentioned by Fresh Energy that have a minimum of zero and a non-zero maximum are not erroneous. We summarize an explanation here, and note that our response to MPUC Information Request No. 3 provides further explanation. In summary, the location drives hosting capacity; the tabular minimum and maximum hosting capacity values correspond to different locations on the feeder. System impacts resulting from DER varies by location on the feeder. Some locations have zero remaining hosting capacity based on existing system conditions, including installed DER, feeder loading, and electric system characteristics. It is very possible that a feeder could have zero minimum hosting capacity, but have a non-zero maximum hosting capacity.

3. 2017 HCA Feeder Characteristics

In response to the request for additional data regarding feeder characteristics by sector (e.g., percent residential, percent commercial), loads are allocated to customers and transformers through the Synergi Electric Customer Management Module (CMM). At its core, the CMM is integrated with our customer billing system, which pulls each customer's monthly kWh consumption and rate class (residential, commercial, industrial, etc.) on a monthly basis.

The CMM data is integrated into the Synergi model through the relationship between customers and the service transformers that supply them – this relationship exists and is maintained in our Geospatial Information System (GIS). When this customer information is loaded into a Synergi model, each customer's kWh consumption for the selected month is used in conjunction with a typical load profile for the corresponding rate class to estimate that customer's peak load.

The customer count, total kWh consumption, and total peak load is aggregated for each service transformer and allocated to the model. Estimated peak load is then expressed in the Synergi model at the granularity of the distribution service transformer; estimated peak loads are not necessarily shown for individual customers. Any information about rate classes for individual customers is only available in the entire CMM dataset – not in the Synergi model.

To provide information on feeder characteristics by customer class would require an extensive effort; this information is not presently available in the Synergi models used for the HCA. We would need to gather the customer class information and cross-reference it with service transformer information across multiple systems. Gathering this information in a geospatial format could provide a separate visual of how customer rate classes are geographically dispersed on a feeder. However, this would not provide an estimate of how much power each customer type consumes; rather, how many customers of each type reside on a feeder. With the significant effort necessary to accomplish this, it would be important to understand how it aligns with the HCA objectives. We would also need to consider whether there are any grid or customer privacy, confidentiality, or security concerns by portraying customer densities in this manner.

4. Potential Use of Sensitivity Analyses

The hosting capacity results provide realistic assumptions that can provide a meaningful first look at hosting capacity potential. Without performing further analysis to determine tradeoffs associated with modifying the assumptions, initiating a sensitivity analysis can only provide partial, and potentially misleading, information. Using the send-out voltage suggestion by Fresh Energy as an example, decreasing the send out voltage from 104 percent of nominal will increase hosting capacity on feeders constrained by primary overvoltage. This decrease is unrealistic on many feeders due to the need to maintain adequate voltage under heavy loading conditions when the DER is not online. The HCA results are not intended to be detailed load flow results, and thus this under-voltage condition may not be caught. In this case, the results of the sensitivity analysis would be meaningless and potentially misleading to users of the tool.

5. Company Analysis of 2016 Results

Our 2017 report included a summary of our work to assess the accuracy of our 2016 Hosting Capacity results. We agree with parties that our analysis did not turn out to be ideal. As we have discussed, the topic of HCA accuracy is an industry issue that others are also attempting to get their arms around. That said, we acknowledge that our narrative would have benefited from additional discussion regarding the results.

For example, Fresh Energy asks why we took an approach that was difficult to effectively compare and that resulted in a sample size smaller than they would have expected. A robust accuracy analysis across many feeders is a large undertaking that not only involves the available hosting capacity results, but also unique detailed interconnection studies that are data- and time-intensive. In fact, it is so time-intensive that we contract a large portion of our interconnection studies out to third-party engineering companies, because we do not maintain the resources to complete them in-house. For our analysis of 2016 results, we utilized only interconnection studies that had previously been completed on our system, and that matched the DRIVE capabilities and the thresholds that were chosen. We discussed the challenges that we faced in this analysis on pages 17 and 18 of our report. We chose to maintain our course with the resulting 15 feeders in an effort to balance resources and expected benefits.

This industry is also struggling with how to best assess accuracy without expending extraordinary resources. Consequently, there is some industry movement underway that we believe will be helpful to inform our analysis in Minnesota. The first is the impending report conducted by EPRI and SDG&E that documents the differences, or lack thereof, of the ICA iterative capacity analysis method using Synergi (the same as our underlying planning software) and EPRI's DRIVE tool. Second is an effort that is just forming between EPRI and a handful of utilities, including Xcel Energy, that seek a better understanding of how their HCA results compare, which we also mentioned earlier in this Section. This EPRI effort is scheduled to begin in 2018 and is expected to also provide meaningful information with regard to accuracy in a way that is not financially and resource burdensome on individual utilities. We believe it is more beneficial to engage and learn from this industry, DRIVE-specific initiative – and where several utilities can share in the significant costs and time involved – than it is to narrowly focus on one utility and one HCA.

Finally, when considering accuracy of results, it is important to focus on the objective of the HCA. If the objective is to inform the interconnection process, we believe our HCA is achieving that by providing information that is useful in making decisions on where DER may be accommodated on the system. If the objective is to approve applications and precisely hit the level of hosting capacity available, then more rigor is not only needed by Xcel Energy – it is needed industry-wide. This is not the present goals for the Minnesota HCA – and as we noted previously, EPRI concluded that this is not a realistic goal with present HCA methods and tools.

We agree with stakeholders that accuracy is important. We are committed to work with EPRI and others toward developing assessment methods that appropriately balance resources and provide value. We offer to report on our efforts with EPRI in conjunction with our 2018 HCA.

C. Potential Improvements to Future HCA Reports

As we have noted, we recognize that the HCA is a work in progress. Parties had a number of suggestions regarding potential improvements to our 2018 analysis, which we discuss in this section.

1. Heat Map Improvements

Several parties suggested that pop-up windows containing various information would be a helpful addition to our next heat map. We have a team working to identify a method to incorporate pop-ups in the map that will allow users access to additional data. At this time, we are cautiously optimistic that we will be able to add this functionality in our 2018 HCA heat map, but note that there are several issues that remain to be solved.

While we appreciate the intention of the "click and claim" concept brought forward by IREC, it is unclear if this is realistic for large DER systems due to the site control, permitting, and financing other issues not related to the electric system. As we have discussed, we suggest that interconnection processing be addressed comprehensively as is underway in the open statewide interconnection standards proceeding – and as part of that, target enhancements for streamlining the overall process.

2. More Frequent Updates

Several parties suggested that more frequent updates to the HCA would be helpful. Our current processes and methods would require that we substantially increase the resources devoted to working on HCA, which we are working to balance with other distribution-focused initiatives and proceedings underway. We are however, working to determine a method whereby we could update the heat map more frequently without the need to dedicate such a substantial amount of incremental resources. If we determine we are unable to do this as part of our 2018 HCA, we will provide the status and a summary of our efforts in our 2018 HCA report.

Similar to the request for more frequent updates, Fresh Energy requested that we use DRIVE to provide developers with the most updated minimum and maximum hosting capacity and limiting factors as part of the capacity screen review in the interconnection process. It important to clarify that our HCA results already account for projects with signed interconnection agreements that have not yet been built. So, our HCA is already providing results that are forward looking. We believe reprocessing this information for every capacity screen received would provide little benefit beyond what is already publicly available today.

3. Additional Information

The Department noted that our Table 3 provides a useful overview of the potential mitigation options available to increase the hosting capacity at individual feeders, and asks whether the overview could be supplemented in future reports. The Department offers potential supplemental items that may provide stakeholders with a broader understanding of the technical and economic potential of the potential of the distribution system.

We currently provide potential mitigations for the specific threshold that was violated. However, there may be ways to expand upon this information, such that it would provide an enhanced understanding of the potential technical and economic ramifications of the identified mitigation. While we do not have a specific proposal on how to accomplish this at this time, we are examining potential enhancements that would expand this content in a meaningful way with our 2018 HCA.

D. Party Questions

Parties request answers to specific questions, which we provide below:

1. Minimum Hosting Capacity Results of Zero

Fresh Energy requests additional explanation of the feeders that have zero minimum hosting capacity, and suggests that perhaps there is a correlation between substations with large amounts of solar gardens active or in development and substations with zero minimum hosting capacity.

Large solar garden projects impact the available hosting capacity and may account for a "zero" hosting capacity result. However, there are other factors that can also impact a zero HCA result. For example, existing wind generation, modeled solar gardens that are no longer proceeding – or, there are some feeders that just have no available hosting capacity for large installations. We examined the nine substations noted by Fresh Energy and found that four appear in the queue (Lester Prairie, Medford Junction, Tracy Switching Station, and Veseli), and the remaining others have zero minimum hosting capacity due to a mixture of the other issues we noted. To the extent some of the projects result in upgrades to the distribution system, these upgrades are to accommodate that project; the upgrades may or may not result in adding additional hosting capacity to the system that would be available to others. For example, if the feeder limitation for a DER interconnection is based on a conductor thermal rating, the conductor is upgraded. Conductors are specified in standardized sizes and offer a discrete increase in capacity when moving up by a single conductor size. The project causing an upgrade may or may not choose to specify a DER project size that uses the entire rating of the newly upgraded conductor.

We note that just because there is zero minimum hosting capacity, it does not preclude a party from submitting an interconnection request at that feeder. In those instances, we have informed anyone wanting to interconnect that hosting capacity is limited – and warned that there will likely be mitigations needed, such as use of inverter functions or system upgrades, if they want to proceed. An interconnection study is the best route to determine the degree of needed mitigations.

2. Daytime Minimum Load Assumption in Absence of Actual Information

IREC asked several questions regarding the 20 percent daytime minimum load (DML) used in our HCA. We have previously discussed this at length, and continue to believe it is a reasonable assumption. While we have SCADA on approximately 70 percent of our feeders, we use the 20 percent DML on 100 percent of the feeders. If we had the DML on all of our feeders and used these actual values in our analysis it would double the number of feeder models we would need to create, which is already a resource-intense process. We agree that using actual DML would provide a more accurate analysis on some feeders. However, for the reasons we have previously described and considering the resources that would be required, this approximation is reasonable for the intended purpose of informing potential interconnections.

3. Over-Voltage Limiting Factor

We were asked to further explain our response to MPUC Information Request No. 1. Specifically, what we mean by "Voltage regulation is not examined in this (primary over-voltage) analysis;" why voltage regulation is not included in the over-voltage analysis; and, how much additional minimum hosting capacity would be available if it were.

The primary overvoltage analysis is a "steady-state analysis," which means that the impacts of load or generation changes on a second-by–second or minute-by-minute are generally ignored. This includes changes in voltage resulting from load tap changer or line regulator operation. In this way, the primary overvoltage threshold is determining if high voltage will occur when all load and generation is constant. Using a send-out voltage approximates the voltage regulation position for a given load condition, since voltage regulation equipment operates on the principle of targeting a send-out voltage.

The voltage regulator deviation threshold is separate from the primary overvoltage threshold and does in fact analyze the voltage change impact at voltage regulators between two steady state conditions – generation-on and generation-off for a given load scenario (i.e. minimum load or peak load). This threshold is intended to prevent voltage fluctuations and reliability issues associated with increased voltage regulation equipment operation.

4. DRIVE Tool

We were asked to explain various aspects of the DRIVE tool, as follows:

Whether DRIVE can be modified to analyze the actual mix of resources on Xcel's system rather than forcing a choice between large centralized and small distributed resources. The DRIVE tool currently uses the actual mix of resources present on our system and their locations. However, DRIVE requires the user to choose a distribution method for how *future* DER is allocated to project the DER growth on the system. We chose the Large Centralized method based on the type of predominant DER growth seen in Minnesota currently affecting hosting capacity. This method combines with the actual mix of resources currently on the system to produce the HCA results.

Whether the DRIVE tool is capable of modeling storage as a load or potential replacement for transmission – and what standards, if any, exist to fully define the requirements or characteristics of storage operating as a source of load or substitute for transmission. DRIVE can currently model storage as a load. However, due to the complexities of storage acting as both a generator and load – especially on a large scale – and the evolving knowledge and nature of the applications,[12] we believe these installations are best handled with a detailed study analysis.

DRIVE's ability to incorporate potential mitigations like a volt-VAr response. We discussed this in our response to MPUC Information Request No. 5. In summary, the voltage-active power (Volt-Watt) and voltage-reactive power (Volt-VAr) control modes are not currently available in the DRIVE analysis. Our 2017 HCA did not include response to abnormal conditions, such as voltage or frequency ride-through. Hosting capacity typically analyzes steady state or quasi-steady state (*static*) conditions, which would not capture the time scales associated with brief system disturbances and DER

[12] Energy storage can typically be specified to operate in numerous different control modes, each having specific tariff and technical considerations to review.

ride-through capabilities. We are not aware of any hosting capacity analysis that includes ride-through capabilities, as these would typically be studied using *dynamic* analysis software typically found in transmission engineering.

If the Volt-VAr function were used in hosting capacity analysis, the results would largely depend on how the function was used. The same is true for the fixed power factor of 0.98 that was used in the 2017 results. The DRIVE tool has the capability to set a lower power factor, which is likely to increase hosting capacity in some locations. We did not choose a lower power factor because trade-offs exist; for example, increased reactive power flow and losses.[13] We have and will continue to use a lower power factor, such as 0.95, as the result of a detailed study where the trade-offs can be reviewed.

The situation is similar for Volt-VAr. A default Volt-VAr curve may provide similar results to the non-unity fixed power factor in many locations. Volt-VAr may be an effective tool for managing voltage in contingency situations, but the DRIVE tool currently only looks at normal configurations. Similarly, the Volt-Watt function is aimed at resolving voltages that occur under abnormal conditions. The Volt-Watt function actually curtails real power output (DER capacity) in order to bring voltage back into the acceptable range. While this may be an important tool for utilities to manage DER in abnormal configurations, the Volt-Watt function is not anticipated to increase hosting capacity under normal configurations.

5. Other

We received a question asking for an explanation regarding how and when load curves based on actual customer data will be incorporated into the analysis. We use typical load curves for our load allocation process. In order to use actual load curves we would need to first install Advanced Metering Infrastructure (AMI) to capture that information at the customer level.

E. Procedural Issues

Minn. Stat. § 216B.2425 requires three substantive sets of reporting: (1) a Biennial Transmission Projects Report; (2) a Biennial Grid Modernization Report; and (3) a Distribution Study/Hosting Capacity Report. As part of its completeness analysis, the Department discusses our service of the Hosting Capacity Report and whether it should have been filed *in* the November 1, 2017 Transmission Biennial Projects

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[13] The increased reactive power flow can reduce hosting capacity in instances where thermal limitations exist.

Report in Docket No. E999/M-17-377. We believe the approach we took, where we filed the Hosting Capacity Report in a separate docket and stated that we had done so in both the Biennial Transmission Projects Report and our Grid Modernization Report filings made the same day in Docket Nos. E999/M-17-377 and E002/M-17-776, respectively, is substantively consistent with the statute and the Commission's Order in our first/2015 Grid Modernization report proceeding.

In that proceeding, the Commission required our first Hosting Capacity Report to be completed by December 1, 2016 "for inclusion *in the 2015 Biennial Distribution-Grid-Modernization Report.*[14]" [emphasis added] We further discuss our thought process and actions below, and agree with the Department that this issue would benefit from Commission clarification for future reports.

Our thought process in making the Hosting Capacity Report a separate filing rather than a subset or section in the Biennial Transmission report or the Grid Modernization Report was as follows:

- The Biennial Transmission report is a joint report with other transmission owners; Xcel Energy is the only utility presently required to submit the Grid Modernization and Hosting Capacity reports included in the statute,
- The Commission has ordered that the Hosting Capacity Report be submitted annually, so it has a different procedural cadence than both the Transmission and Grid Modernization reports,
- The Commission previously linked the Hosting Capacity and Grid Modernization Reports by ordering that the first Hosting Capacity report be submitted on December 1, 2016 "for inclusion in the 2015 Grid Modernization Report,[15]"
- The Commission has a "June of the following year" statutory requirement to take action on the Grid Modernization Report,
- The Hosting Capacity Report is substantive in nature and implicates substantive issues; thus, it seems out of place to make it a section within or attachment to a report on a completely different subject, and

[14] *See* Order Point No. 3, ORDER CERTIFYING ADVANCED DISTRIBUTION-MANAGEMENT SYSTEM (ADMS) PROJECT UNDER MINN. STAT. § 216B.2425 AND REQUIRING DISTRIBUTION STUDY, Docket No. E002/M-15-962 (June 28, 2016).
[15] *See* Order Point No. 3, ORDER CERTIFYING ADVANCED DISTRIBUTION-MANAGEMENT SYSTEM (ADMS) PROJECT UNDER MINN. STAT. § 216B.2425 AND REQUIRING DISTRIBUTION STUDY, Docket No. E002/M-15-962 (June 28, 2016).

- The parties that have typically engaged in the topic of hosting capacity differ from parties that have typically engaged in transmission issues and the broader grid modernization topic.

We believed that cross-referencing the Hosting Capacity report in the Grid Modernization report and serving it on the Grid Modernization and 2016 Hosting Capacity Report service lists would meet the spirit and substance of the Commission's Order regarding the first/2016 Hosting Capacity report. We also believed it would be more manageable procedurally, and also be more user-friendly for parties. Out of an abundance of caution, we also cross-referenced it in the Transmission Projects Report, and touched-base informally with Commission Staff regarding our plans for the three topics/reports in advance of filing. However, as the Department observes, the service lists that we used for the Hosting Capacity Report did not include *all* parties to the Biennial Transmission report. Specifically, there are 12 parties on the Transmission report list that were not on the service list that we used for the Hosting Capacity Analysis.

The Department notes that we effectively met the procedural requirement and arguably, may have improved on it by focusing the service on parties that are interested only in the distribution system. However, the Department recommends that the Commission decide – and make explicit in its Order – whether filing the Hosting Capacity Report in a separate docket is a permissible interpretation of the statutory requirement that the Report be included *in* the Biennial Transmission Projects Report. As we have noted, we believe that given the history of how the Commission has set the filing expectation for the Hosting Capacity Report, that our service was appropriate. However, we would appreciate the further clarity that the Department recommends.

The Department also recommends that we either notice the parties to the Transmission report that were not part of the Hosting Capacity Report service, or confirm they do not want to be included. We believe the parties to the Transmission report have been advised that the Grid Modernization and Hosting Capacity reports were filed separately by both the Company and the Commission, and therefore have had the opportunity to engage in the proceedings, as we discuss below. We have therefore not made any additional notice at this point.

1. Procedural Treatment of Previous Grid Modernization and Hosting Capacity Reports

We filed our first Grid Modernization Report on October 31, 2015, as part of the then-current Transmission Biennial Projects Report in Docket No. E999/M-15-439.

On November 4, 2015, the Commission assigned it to a separate docket (Docket No. E002/M-15-962). The Commission's June 28, 2016 Order in the E002/M-15-962 docket required the Company to complete and file its Hosting Capacity Report by December 1, 2016 "for inclusion in the 2015 Biennial Distribution-Grid-Modernization Report." We filed our first Hosting Capacity Report on December 1, 2016 in the E002/M-15-962 docket. The Commission's August 1, 2017 Order in that docket required *annual* filings of the Hosting Capacity Report, which differs from the biennial pace of the Biennial Transmission Projects Report. We viewed this as additional confirmation that the Hosting Capacity Report should be on a separate path.

2. Transparency of Procedural Treatment in 2017 Reports

We attempted to be transparent in our handling of these various reports. In the November 1, 2017 Transmission Biennial Projects Report in Docket No. E999/M-17-377 at page 2, there is a specific reference to the fact that the Grid Modernization and Hosting Capacity Reports were being filed in separate dockets:[16]

> *… In 2015, the Legislature established a new reporting requirement for certain utilities. Minn. Laws 2015, 1Sp2015, ch. 1, art 3, s 22, codified at Minn. Stat. § 216B.2425, subds. 2(e) and 8. This reporting requirement is explained in further detail in Chapter 2, subsection 2.6. Pursuant to that requirement, Xcel Energy (currently the only utility to which the requirement applies), has submitted two separate reports entitled (1) Grid Modernization Report and (2) Hosting Capacity Report to the Minnesota Public Utilities Commission in separate dockets.*

The Commission issued a Notice on November 9, 2017 setting the comments period for the 2017 Transmission Biennial Projects Report. This Notice also referred to the separate dockets for the Grid Modernization and Hosting Capacity reports, as follows (in relevant part):

> *Beginning with the 2015 Biennial Transmission Projects Report, Xcel Energy is required to file a biennial Grid Modernization Report and a Hosting Capacity Report. The Commission will solicit comments on Xcel's Distribution Grid Modernization Report and Hosting Capacity Report in two separate dockets; No. E002/M-17-776 and E002/M-17-777, respectively.*

This further supports our belief that our procedural treatment was proper, and that parties to the Transmission Biennial Projects Report have been notified that the other reports have been filed in separate dockets. Finally, we note that this procedural service issue was not identified in completeness or other comments in the Biennial Transmission Projects Report proceeding, nor in comments in the Grid Modernization Report proceeding.

[16] There is a similar statement on page 9.

For the reasons we have described, we believe the way we submitted, served, and linked the Hosting Capacity Report with the Biennial Transmission Projects and Grid Modernization Reports was proper. The Commission's November 9, 2017 Notice functioned as further notice to the 2017 Transmission Biennial Projects Report service list that our Hosting Capacity Report and our Grid Modernization Report were in different dockets. Given these cumulative facts, no interested party has been denied appropriate notice of the pendency of the current docket and no interested party has been denied the opportunity to be heard in the current docket.

We recognize however, the procedural path for these filings is not as clear as would be typical for an annual report. We therefore agree with the Department that it would be helpful for the Commission to clarify its procedural expectations for future reports. To the extent the Commission agrees with how we have handled the 2017 series of reports, it could direct the Company to handle future reports in a similar manner when they align with the biennial timing specified in the statute. However, the Hosting Capacity Reports are on an annual cycle – and we have requested approval in Docket No. E002/M-17-776 to submit an annual Grid Modernization Report in 2018, and annually thereafter at least through 2022. We would therefore appreciate additional clarity regarding the expected procedural treatment for the years in which these distribution reports do not align with the Biennial Transmission Projects Report.

CONCLUSION

We appreciate the opportunity to respond to Parties' comments. Our HCA is meeting the objectives set-out in statute and by the Commission. We acknowledge that our HCA is a work in progress like other leading utilities, and we appreciate the engagement of stakeholders to help inform the industry path as the issue of hosting capacity analysis and related processes mature. We are committed to monitoring, learning, and continuing to evolve and improve our HCA as the industry continues to undergo change.

Dated: February 28, 2018

Northern States Power Company

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RESEARCH INSTITUTE

Impact Factors, Methods, and Considerations for Calculating and Applying Hosting Capacity

2018 TECHNICAL UPDATE

Impact Factors, Methods, and Considerations for Calculating and Applying Hosting Capacity

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Technical Update, February 2018

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EXECUTIVE SUMMARY

Introduction

The industry is increasingly faced with making decisions on how to evaluate growing penetrations of distributed energy resources (DER). New sets of challenges for planning and operating the grid, especially on the distribution systems that serve these new resources, has arisen. With these challenges in mind, utilities across the world are beginning to look at new analytical methods that help assess and integrate DER into the distribution system. A foundational element of such assessments is the capability to evaluate the ability of distribution systems to "host" DER capacity – aka hosting capacity.

The range of DER a feeder can host depends on a wide range of factors, some of which are well known (DER location, DER type, feeder configuration, etc.). However, there are a wide range of additional factors that significantly impact hosting capacity – mainly the inputs and assumptions used for DER and grid models used for the analysis. This report will unpack these impact factors and provide context around how hosting capacity is affected.

> 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.

The concept of hosting capacity is not new, but its application is becoming more widespread as the industry needs a comprehensive approach to understanding the impacts of DER. The three main applications for hosting capacity identified are:

1. Informing the public
2. Assisting interconnection screening
3. Enabling planning with DER

Lastly, various hosting capacity methods have been developed in the recent years resulting in considerable debate regarding which "method" should be used and when. This report also provides an overview of the current state of methods, addressing common misconceptions, advantages/disadvantages of various approaches, as well as provide recommendations on application.

This report will address all three of these major topics: factors that influence hosting capacity results, methods used throughout the industry, and recommendations on method applications to inform the industry on these important considerations.

Hosting Capacity Applications

The growing penetration of DER on the electric grid has created a new set of challenges for planning and operating the grid. With these challenges in mind, utilities across the country have begun to determine how to consider these resources in their regulatory planning process.

Industry Status

In New York, the utilities have defined a structure for a transparent planning process across each utility and identified where and how DER can be integrated. This was in response to the New York State Public Service Commission's Reforming the Energy Vision initiative aimed to more fully integrate and utilize DER with distribution planning and operations. A key component was to release hosting capacity maps[1] to identify where DER can be accommodated on their systems. The utilities laid out a roadmap for a consistent approach to hosting capacity for NY with a primary application of informing developers and enabling planning.[2]

In Minnesota, Xcel Energy recently released hosting capacity maps and values in an effort to inform developers and better enable distribution planning with DER.[3] Xcel's efforts were in response to the Minnesota Public Utilities Commission's Grid Modernization efforts to encourage utilities in maintaining system reliability, improving efficiency, and enabling further customer choice. Xcel Energy focused on an Integrated Planning Process that would meet the needs of the future with hosting capacity as a key piece in the analytical framework.[4]

In California, the investor owned utilities have each outlined a Distribution Resources Plan geared at enabling the identification of where DER can be best integrated on the system. A central discussion point in California has been in determining a hosting capacity method – Integration Capacity Analysis – to be utilized consistently across the state. The California Public Utilities Commission requiring these developments has been particularly focused on enabling the identification of where DER can be best integrated in order to inform developers, improve interconnection and planning.[5]

A common element of all of these efforts has been in defining analytical methods (hosting capacity) that identify impacts of distributed resources in the electric system.

Industry Applications

Hosting capacity is becoming a key component of system planning as utility processes begin to change with the increase of DER. To date, the main application for hosting capacity is to determine how much DER can be accommodated on the system as-is today and identify the limiting issues that may arise. In turn, the utility can inform stakeholders and assess integration solutions to mitigate the issues. The hosting capacity calculations can also be overlaid with maps

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[1] http://jointutilitiesofny.org/utility-specific-pages/hosting-capacity/

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

[3] https://www.xcelenergy.com/working_with_us/how_to_interconnect/hosting_ capacity _map

[4] https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method =eDocketsResult&userType=public#{F01C795F-0000-C81D-9319-32CC6BC16E25}.pdf

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

to inform developers of locations where issues are more or less likely to occur. Additionally, it can be used to assist with interconnection screening and planning decisions.

Whatever the application, the hosting capacity assessments should consider a wide range of grid impact factors. The range of DER a feeder can host depends on the location and characteristics of both the feeder and DER. Hosting capacity will change over time as load, DER and circuit configurations change.

Informing the Public

As DER interconnection queues grow across the country, there is a need to provide developers and customers with greater visibility into where on the system interconnection applications may require additional cost to be accommodated.

Assisting with Interconnection Technical Review

With increased numbers of DER interconnection applications and growing queues, there is greater focus on the ability to perform technical review of sites quickly and accurately. Hosting capacity can play a role in informing this process and help utility engineers in decisions on approval or need for further study.

Enabling Planning with DER

To effectively plan and operate the distribution grid, engineers must account for the DER characteristics and the location the resources are connecting. As the distribution system becomes more integrated, planners will need to utilize analytical methods like hosting capacity that allow the system to be designed while capturing the range of operating conditions.

Hosting capacity is also an important part of scenario planning used to evaluate different what-if cases. It can be enhanced with load and DER forecasts to evaluate planning scenarios and quantify a range of potential future impacts. Under these scenarios, utilities can evaluate mitigation factors, infrastructure upgrades, as well as system-wide cost benefit assessments. In the future, this enhanced level of analysis will enable utilities to determine the ability of the distribution system to utilize services from DER (non-wires alternatives – NWAs), the impacts of DER on grid reconfiguration, operational strategies, and smart inverter technologies.

Hosting Capacity Methods – A Quick Preview

As hosting capacity has become a focus of efforts across many jurisdictions, there has been great attention on the different methods that are being employed to calculate hosting capacity, including:

- What are the differences between the methods?
- Which method is most accurate?

This report details the presently available methods used throughout the industry in the chapter Methods for Determining Hosting Capacity. In this chapter each method is described in detail including dedicated sections covering:

- Overview
- Common misconceptions
- Assumptions
- Implementations
- Input, storage, and computation reqs
- Advantages/disadvantages
- Recommendations

- Which method can be used for particular applications?
- What is the best approach moving forward?

These are the right questions being asked, however the answers are quite complex. This paper will attempt to unfold these questions and provide answers in a manner that is informational for both engineers performing the assessments to the stakeholders using the results.

Where are we now?

Due to the varying intended uses, some jurisdictions have approached the challenge of creating hosting capacity "methods" differently. As such, the industry has adopted terms such as stochastic, iterative, streamlined, hybrid, etc. in an attempt to differentiate between different methods. While this is helpful in referring to different approaches, to some extent this has created some confusion as these are somewhat ambiguous terms and up for interpretation. This is increasingly difficult as methods are still relatively new and rapidly evolving. For the sake of consistency within the industry, this report will refer to the various methods using these industry "labels" thus far established (stochastic, streamlined, iterative, hybrid).

Table 1 provides a glimpse into how the methods are presently unfolding. At present, California has adopted what is referred to as an "iterative" approach (much consideration was given to PG&E's "streamlined"), while other jurisdictions such as New York, Minnesota, et al. have adopted a "hybrid" method utilized within EPRI's DRIVE. Likewise, the intended use cases in the various jurisdictions have varied as well and that has driven many of the discussions and decision making.

Table 1
Range in Hosting Capacity Implementations Developed in Recent Years

Method	Industry Adoption	Recommended Use Case
Stochastic	Pepco, ComEd	+Enabling Planning +Informing the public
Iterative	SCE, SDG&E	+Assisting with Interconnection +Informing the public
Streamlined	PG&E	+Enabling Planning +Informing the public
Hybrid – DRIVE	>27 utilities worldwide (including Xcel, NY)	+Enabling Planning +Assisting with Interconnection +Informing the public

Selecting a Hosting Capacity Method

Whichever method is selected, it should be flexible enough to meet the range of present and future application needs. There are seven main components EPRI recommends considering when evaluating hosting capacity methods. The method should provide enough **granularity** such that it can distinguish the important factors that most affect hosting capacity: location, feeder design and operation, and DER technology. Requirements do not stop there, however. The method should also be **scalable** in order to analyze entire distribution systems but also **repeatable** to consider individual feeder modifications. **Transparent** and **proven** methods should also be used in order to gain confidence. Lastly, the method should be **available** such that readily accessible data and distribution planning tools can be utilized and **consistent** application can be done across various jurisdictions and planning tools.

Granular	•capture unique feeder-specific responses
Repeatable	•as distribution feeders change
Scalable	•system-wide assessment
Transparent	•Clear/open regarding what is calculated
Proven	•validated techniques
Available	•utilize readily available utility data & tools
Consistent	•across different jurisdictions

Figure 1
Fundamental Components of a Flexible Hosting Capacity Method

There are additional considerations when selecting a method, a few of which are how results will be applied, computation time, and frequency of updates. These and many more considerations are summarized in the final chapter ***Consideration for Hosting Capacity Applications.*** In this chapter, each of the three use cases are expanded upon as it relates to the use of hosting capacity.

Hosting Capacity Impact Factors

A great deal of attention throughout the industry has focused on the methods used to calculate hosting capacity, however one that has been somewhat overlooked and can have a much greater impact on hosting capacity results, are the factors that influence the results – the actual methods inputs and associated assumptions that go into them.

The capacity of the grid to accommodate and integrate DER is highly dependent upon a number of factors that are difficult, and in some cases near impossible, to consider in entirety. The many factors that drive hosting capacity have varying degrees of impact, sometimes opposing and other times complimenting each other. Hosting capacity, like all model-based calculations, is an approximation of the potential adverse impacts of DER to distribution systems. As such, effective use requires thoughtful consideration of the input assumptions and associated hosting capacity impact factors. Proper consideration of the assumptions and factors yield useful outcomes for various utility and stakeholder applications.

Impact		Hosting Capacity Impact Factor
High	DER	Location
High		Type/Technology/Portfolio
High		Smart Inverter
High		Communication and Control
High		Aggregation
Medium		Efficiency
Medium		Single-Phase
Low		Vendor
Low		Plant layout
Medium		local weather patterns (renewables)
Medium		Panel orientation (PV)
High	Distribution	Voltage control scheme
High		Configuration/reconfiguration
High		Load level and allocation
High		Phasing information (load/laterals)
High		Protection system design
Medium		Granularity of MV models (# of nodes)
High		Grounding practices
High	Misc	Time
Medium		Modeling of service transformers
Medium		Modeling of services/secondaries
Low		Planning software platform
Medium		Transmission constraints
Medium		Transmission grid configuration/dispatch

Figure 2
Relative Effect of Hosting Capacity Impact Factors

This report also expands upon this topic in the chapter **Hosting Capacity Impact Factors** and provides better context into how hosting capacity results can vary and why.

Conclusions

The industry's understanding and application of hosting capacity calculations have come a long way and will continue to be a vital piece of the approach when considering DER on the distribution system. This report outlines the important considerations when it comes to implementing a hosting capacity analysis for the purpose of informing interconnection, planning, and developers. Specific takeaways include:

1. **Comparison efforts thus far have been premature.** A great deal of work has been done to date in an attempt to compare the various methods however many of these comparisons were premature and limited in scope. For example, the comparative analysis performed in California evaluated two approaches (streamlined and iterative). The streamlined approach, which was new and still under development, was compared to that of iterative. While the iterative approach was more mature, it too was under development. Additionally, this comparative analysis did not consider further developed methods that were also available in the industry such as DRIVE. While this comparison was informative it was not comprehensive nor definitive. Given this example, work needs to be done to provide more comprehensive comparisons.

2. **Different hosting capacity methods can provide similar results.** EPRI has recently demonstrated, working with San Diego Gas & Electric to compare DRIVE to the Iterative ICA method, that different methods can in fact produce similar results. The hybrid DRIVE method was found to produce the same results as that found in the California Iterative ICA method. Based on this, there are opportunities for the industry to continue to refine and enhance multiple hosting capacity approaches while still achieving consistent results.
3. **Mandating how hosting capacity should be calculated sets the industry up for costly risks.** Mandating the mechanics of how hosting should be calculated is a risk and discourages innovation. Also, it does not leverage new analytics being developed within the industry to meet the growing needs and prohibits effective integration of emerging technologies. This risk has been observed already in California where the iterative approach was adopted, but operational flexibility calculations are having to rely on heuristics due to the computational intensity. The concern raised is that it may lead to unnecessarily limited hosting capacity in some cases.
4. **Hosting capacity analytics will continue to evolve making it more difficult to draw clear distinctions between "methods."** While this report outlines each of the four main hosting capacity methods, in some cases it is difficult to draw clear distinction between them. As demonstrated here, hosting capacity methods have and will continue to evolve. While the industry has tried to draw a distinct line between various approaches, mainly "iterative" and "streamlined", in the future this will be irrelevant as there will likely be little means of distinction. In some cases, results seem to indicate "iterative" type approaches are beginning to adopt the mechanics of "streamlined" techniques and vice versa. Hybrid approaches, such as that used within DRIVE, have also been developed wherein "iterative" type results are achieved using enhanced "streamlined" methods. The labels used in the industry for describing different methods will eventually be irrelevant.
5. **Methods are important, but the results are what matter most.** Hosting capacity is a complex analytical assessment. While the methods utilized to calculate hosting capacity are important and each have pros and cons that must be understood, it is recommended to focus more on the method results. Because methods are evolving, ongoing comparisons and validation are important to ensure that results continue to be meet industry expectations. As such, EPRI recommends transparency of results more so than the underlying algorithms used. Similar to smart inverter functions, rather than mandating manufacturers share complicated algorithms, the inverters are instead simply tested in order to evaluate performance. Likewise, EPRI recommends developing and publishing results from test feeders thus allowing the industry to compare and validate results consistently as methods continue to develop.
6. **Hosting capacity results are driven by the impact factors considered.** Methods matter, but so do the input data assumptions and factors considered. Not all impact factors can be considered, therefore careful consideration evaluating the appropriate impact factors is key to improving result accuracy.
7. **A hybrid hosting capacity method is the most likely path forward.** As hosting capacity methods evolve, method distinctions become even harder. As methods adopt best practices from other methods and further evolve, approaches will converge. Because of this, EPRI

believes that a hybrid approach rather than one that is exclusively "streamlined", "iterative", or "stochastic" will be most successful going forward.

8. **Ongoing advancements and improvements are critical as needs become more complex.** Further innovations in hosting capacity analytics will be critical as the distribution system becomes even more complex. Grid modernization initiatives, using DER as non-wires solutions, transactive energy, all of these changes will increase the complexity of distribution analysis. Hosting capacity analytics are a key component in the assessment of distribution systems and as such the industry should continue to focus on improving the methods outlined here. Advancements to the capabilities of hosting capacity will be critical to ensuring the results of this analysis capture the needs of tomorrow.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
INTRODUCTION

The industry is increasingly faced with making decisions on how to evaluate growing penetrations of distributed energy resources (DER). New sets of challenges for planning and operating the grid, especially on the distribution systems that serve these new resources, has arisen. With these challenges in mind, utilities across the world are beginning to look at new analytical methods that help assess and integrate DER into the distribution system. A foundational element of such assessments is the capability to evaluate the ability of distribution systems to "host" DER capacity – aka hosting capacity.

> 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.

The range of DER a feeder can host depends on a wide range of factors, some of which are well known (DER location, DER type, feeder configuration, etc.). However, there are a wide range of additional factors that significantly impact hosting capacity – mainly the inputs and assumptions used for DER and grid models used for the analysis. This report will unpack these impact factors and provide context around how hosting capacity is affected.

The concept of hosting capacity is not new, but its application is becoming more widespread as the industry needs a comprehensive approach to understanding the impacts of DER. The three main applications for hosting capacity identified are:

1. Informing the public
2. Assisting interconnection screening
3. Enabling planning with DER

Lastly, various hosting capacity methods have been developed in the recent years resulting in considerable debate regarding which "method" should be used and when. This report also provides an overview of the current state of methods, addressing common misconceptions, advantages/disadvantages of various approaches, as well as provide recommendations on application.

This report will address all three of these major topics: factors that influence hosting capacity results, methods used throughout the industry, and recommendations on method applications to inform the industry on these important considerations.

2
HOSTING CAPACITY IMPACT FACTORS

The capacity of the grid to accommodate and integrate DER is highly dependent upon a number of factors that are difficult, and in some cases near impossible, to consider in entirety. The many factors that drive hosting capacity results have varying degrees of impact, sometimes opposing and other times complimenting each other. **Hosting capacity, like all model-based calculations, is an approximation of the potential adverse impacts of DER to distribution systems**. As such, effective use requires thoughtful consideration of the input assumptions and their associated impacts. When done correctly, these calculations can be extremely valuable and yield useful outcomes for various utility and stakeholder applications.

The challenge of determining hosting capacity is that it is a multi-dimensional problem driven by the specific DER as well as the grid itself. This section will detail the impact factors and recommendations for considering both of these in hosting capacity calculations.

Model-based calculations approximate actual systems and circumstances, particularly when inputs to the models are unknown or have high degrees of uncertainty. As a result, the outcomes are approximations. The more complicated the model and parameters that impact outcomes, the more difficult it is to derive an accurate solution. A good example is the highly complex weather models that predict future conditions differently. Different models yield different results. While one model may be better than another for one set of conditions, the next time another model may prove to be more accurate.

https://en.wikipedia.org/wiki/Tropical_cyclone_forecasting#/media/File:Ernesto2006modelspread.png

Grid Characteristics

There are several grid characteristics that have significant impact on hosting capacity. The main grid impact factors that should be considered include: voltage control, configuration, load, and phasing.

Grid Voltage Control

In many cases, the feeder voltage profile is one of the major impact factors. Even slight variations in feeder voltage profiles can significantly increase or decrease the ability to host DER.

The most common approach utilities use to provide cost-effective voltage control is to deploy assets such as substation LTCs, line regulators, capacitors or combinations thereof. The primary function of these assets is to prevent undervoltage during peak load periods. Typically, settings for these voltage regulation devices are based on rules of thumb and/or default settings. The models used to represent these assets may not have the as-operated field settings incorporated appropriately. Moving forward, this will no longer be adequate and further model verification/validation will be needed to ensure modeling parameters match field settings so the impact to hosting capacity can be captured.

Grid Configuration

While most distribution systems are radial in nature, they typically aren't static in configuration. This ability to reconfigure the distribution system is known as "Operational Flexibility," where the operator has the "flexibility" to open/close switches throughout the system to optimize the delivery of electric service. The primary example is seasonal switching to maintain reliable power quality during routine maintenance. As the grid is further modernized, it will become more and more dynamic in configuration.

The configuration of the grid impacts not only voltage profiles (as noted previously), but also the thermal margins of lines and transformers as well as protection settings. As such, hosting capacity assessments should consider the normal "as-designed" state of the system as well as take into consideration the abnormal or "reconfigured" state of the system. The planning data and tools necessary for such calculations to be performed will need to evolve in order to do so. In the meantime, some utilities have developed rules-of-thumb for estimating the hosting capacity of DER under reconfigured conditions where zero reverse power is allowed to flow through tie switch points.

Load

The amount, location, and type of load along a feeder directly impacts not only thermal loading of assets but also the voltage profile. As such, hosting capacity is impacted by how loads are modeled and assumptions used to develop them.

Loads are represented in distribution models today based on estimates. Due to the sheer number of customers on a distribution feeder (100's-1000's) and wide diversity in customer usage profiles, "average" load models are used to reflect load impacts to distribution. Additional methods are utilized to adjust the magnitude of loads to represent non-peak conditions which are important for assessing DER impacts. However, loads are diverse by nature and difficult to quantify and forecast precisely at the distribution level. Load profiles can vary throughout the day, season, etc. and change year to year as new customers interconnect and disconnect from the grid.

Phasing

Distribution systems are inherently unbalanced in North America. Single phase loads and laterals (branches) are the common practice while most residential homes are served from single-phase lines. This creates an unbalance in load and inherently results in unbalanced voltages. As such, it is important to ensure models represent proper phasing of loads.

Additional Considerations[6]

A number of additional factors have an impact on overall hosting capacity results, including:

- Accuracy of the underlying models (conductor data, transformer parameters, latency in model updates, etc.)
- Modeling the reactive power consumed by customers. These values are usually estimated at a default power factor and are typically inaccurate at low load levels.
- Service transformers and service drops which are not typically modeled
- Planning software
- Grounding practices
- Protection system design
- Granularity of medium voltage models (number of nodes)
- Transmission grid reconfiguration/dispatch

Gaps in Modeling

Considering DER impacts requires utilities to improve how they model their distribution systems. Many utilities are working to further improve their models, while others are developing models of their system for the first time. Improving distribution models requires additional data and engineering effort.

Data such as AMI can help improve modeling outcomes, however most utilities do not currently model their secondary (where AMI measurements are taken) nor have the ability to incorporate it into planning models. While AMI can help, considerable work is still needed to determine effective means of incorporating such data streams to improve the customer-load aspects of distribution models.

Improving on modeling is an ongoing effort throughout the industry. The system is constantly changing in real-time but there is a lag in updating models.

DER Impact Factors

Similar to the grid impact factors, there are several characteristics that should be considered in model-based calculations related to DER impact factors including: location, type, control capabilities, aggregation of DER, and portfolios of different DER technologies.

DER Location

The location of DER on the distribution system is perhaps the most critical DER-specific factor, especially for variable generation technologies such as solar and wind. DER systems interconnected to distribution near the substation (or through express feeders) have a significantly different impact on grid voltage and thermal conditions than if they were connected near the end of the feeder.

DER Type (technology)

Understanding the behavior of particular DER technologies is important in order to define DER characteristics. Variable generation can have widely varying impacts on system response when compared to fixed or dispatchable DER like fuel cells or energy storage. Portfolios of DER must also be considered, such as combined solar and storage. The differences in technologies primarily emanate from:

[6] *Distribution Modeling Guidelines: Recommendations for System and Asset Modeling for Distributed Energy Resource Assessments.* EPRI, Palo Alto, CA: 2015. 3002006115.

- *Output Characteristics.* Intermittent DER, where the output varies throughout the day, can produce voltage fluctuations and/or increased O&M on voltage regulation schemes. In some cases, this can reduce hosting capacity. However, if the DER output is dispatchable such that the DER production is changed (e.g., curtailed) to mitigate adverse distribution impacts, hosting capacity can be increased considerably.
- *Timing.* The time of day when the DER is available to inject/absorb active and/or reactive power also impacts hosting capacity.
- *DER Interface Technology.* The specific DER interface technology (inverter-based) or machine-based also has an impact such as for fault contribution and control.

DER Control

The circumstances and extent by which DER can be controlled can also have a significant impact. When control of active and reactive power is available to the distribution operator, mitigation options can be extended to further increase hosting capacity as well as support the grid.

Operating autonomously, DER can also respond to local conditions based on predefined curves and settings. In cases where the DER is coordinated with grid operations, hosting capacity can increase and grid voltage and/or capacity needs can potentially be met. This is illustrated in Figure 2-1 where the DER power factor is adjusted to increase hosting capacity.

However, when DER is controlled to provide bulk system services (e.g., DER providing frequency regulation service for bulk system), one has to ensure the services can be provided through the distribution system without being limited by local voltage and thermal factors. Under such circumstances, DER hosting capacity may be limited depending upon how the resource is used.

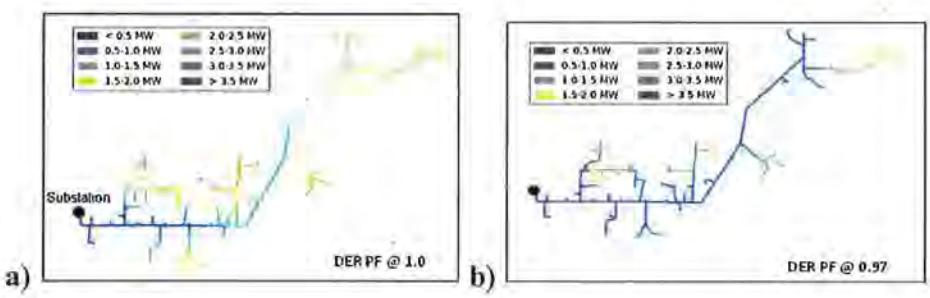


Figure 2-1
Hosting Capacity Map for Impact Factor: DER Control a) Unity Power Factor b) 0.97 Power Factor

DER Aggregate

The impact of DER in one location is highly dependent on the other DER located on the distribution system. Other DER could come in the form of existing installed DER, DER in the interconnection queue, or forecasted DER. In some cases, the impacts of all these DER should be considered in the analysis. Whether other DER limits future levels of DER is highly dependent on the impact factors mentioned previously (DER location and type, etc).

Additional Considerations

A number of additional factors have an impact on overall hosting capacity results, including:

- DER forecasts
- Panel orientation (PV systems)
- DER efficiency
- DER vendor manufacturer
- DER plant layout
- Local weather patterns (renewable resources)

Consideration for Multiple Impact Factors

As discussed, the DER and grid impact factors are a significant driver of the hosting capacity assessments. Figure 2-2 is a sample illustration of the dependence of hosting capacity at a single location to that of the number of impact factors considered in the analysis. As the number of impact factors increases, the accuracy of the hosting capacity results increases as well. To significantly increase the accuracy of the calculation and better understand the full range of hosting capacity one would have to consider all factors.

However, due to computational intensity, data required, and engineering time to do so, this is not recommended. EPRI recommends that analyses focus on impact factors and conditions that identify the lowest (worst-case) and highest (best-case) hosting capacities. This is particularly important when using the results for assisting with interconnection requests and informing developers.

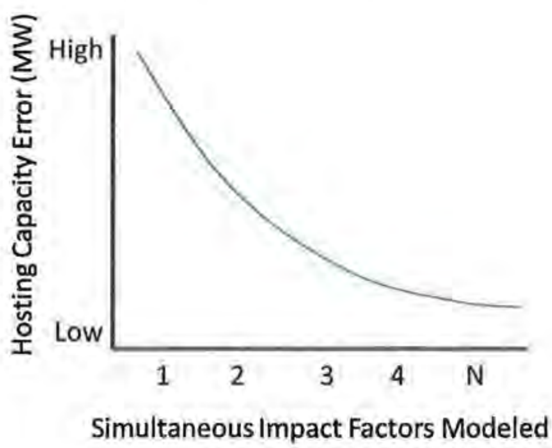


Figure 2-2
Single Location Hosting Capacity

One important point is that the hosting capacity error shown in Figure 2-2 does not converge to zero. Assumptions are necessary due to the uncertainties in underlying data and therefore a single "100% accurate" answer is not achievable. Assumptions around voltage regulation, future load profiles, DER profiles and characteristics, phasing, etc. all impact hosting capacity.

However, if sound assumptions are utilized and the implications are well understood then the outcome can be extremely valuable.

To provide further guidance, Figure 2-3 summarizes each of the impact factors mentioned previously as well as a relative ranking of importance in impacting hosting capacity.

	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

Figure 2-3
Relative Effect of Hosting Capacity Impact Factors

As noted previously, considering multiple impact factors simultaneously can significantly increase the computational burden. Take for example the simple illustration in Table 2-1 where six impact factors are being considered. For a single DER location a total of 24 cases need to be calculated. For this same analysis repeated across an entire feeder this number would increase to 19,200 cases. To further this point, if the analysis considered 576 time periods (per the California Integration Capacity Analysis (ICA) method), this number would reach to over 5.5 million cases for a single feeder!

This simple example does not suggest a specific number of cases should be simulated on a single feeder to capture hosting capacity, but rather demonstrates the complexity of considering the impact factors that affect hosting capacity. As such, a more straightforward approach that utilizes certain grid and DER assumptions can allow the engineer to identify boundary cases that calculate the minimum and maximum hosting capacities without needing the execution of repetitive cases. This subject will be addressed in the following chapters.

Table 2-1
Example of Simulated Cases Needed to Determine Hosting Capacity

Sample Impact Factors	One Location	One Feeder
1 DER locations	1	800
2 DER type	1	1
3 DER control	3	3
4 Queued DER	2	2
5 Grid configurations	2	2
6 Simulated hours	2	2
Total cases	**24**	**19,200**

EPRI Recommendation

DER impacts should be considered just as all grid planning and interconnection is done today – design and study for the realistic, worst-case conditions to ensure adverse impacts to reliability and grid services does not occur for other customers. As such, hosting capacity should consider realistic, worst-case conditions to better understand the potential lower limits but also the best-case conditions to understand the potential upper limits. These realistic boundary conditions should drive decision making.

Eventually, the industry will further evolve such that probabilistic techniques can be used to better quantify the *likelihood* of upper and lower boundary conditions and therefore enable engineers to evaluate the risk of allowing such conditions to exist. Considerable work and research is needed to evolve the data requirements, methods for assessment, and tools to evaluate probabilistic (risk-based) methods for this to be realized.

There are many valuable applications for the results of a hosting capacity study, however, the engineer using those results needs to be aware of the impact factors considered to derive them. It is also critical to understand how those impact factors are, or could be, considered in the applied hosting capacity method.

3
METHODS FOR DETERMINING HOSTING CAPACITY

Methods and the metrics that quantify hosting capacity have evolved over time. The de facto method to determine hosting capacity at a specific location involved the same study used to conduct detailed interconnection reviews. For a detailed study to determine hosting capacity, however, the analysis considered impact factors such as DER types, locations, load levels, protection settings, and engineering judgment. This required running significantly more power flow, fault flow simulations, and engineering time. Needless to say, it was impractical to calculate hosting capacity across entire distribution systems in such a manner as that used in a full detailed study for a single DER interconnection application.

> *No hosting capacity method replicates detailed interconnection studies.*
>
> This detailed study requires engineering judgement to setup and run many power flow and fault flow simulations. It typically involves several software tools and multiple departments (planning, protection, etc.) within the utility.

This spurred the introduction of a hosting capacity method quantified based on the size of the DER but specified due to dominating factors such as DER location, time, distribution configuration, etc. [7] From that, various approaches were developed ranging from stochastic-based methods to iterative and streamlined-type approaches.

All methods have evolved and are still evolving, with their own advantages and disadvantages, based on assumptions used to determine hosting capacity. It is also important to note that none of these methods are considered industry standards, however some have been more broadly adopted then others.

Some jurisdictions have approached the challenge of creating hosting capacity "methods" differently. As such, the industry has adopted terms such as stochastic, iterative, streamlined, hybrid, etc. in an attempt to differentiate between different methods. While this is helpful in referring to different approaches, to some extent this has created some confusion as these are somewhat ambiguous terms and up for interpretation. This becomes increasingly difficult as methods are still relatively new and rapidly evolving. For the sake of consistency within the industry, this chapter will refer to the various methods using these industry "labels" thus far established and will address the following methods:

[7] Smith, J., "Feeder Characterization for PV Integration Assessment," DOE High Penetration Solar Deployment II Workshop, Sacramento, CA, 2011.

- Stochastic
- Streamlined
- Iterative, and
- Hybrid (DRIVE).

Clustering

One alternative approach for analyzing the hosting capacity across distribution systems is to group, or cluster feeders based upon specific characteristics and perform analysis on limited sets of feeders within each group. This approach has shown to be problematic in accurately representing the hosting capacity of other feeders within each group. This approach is only recommended when limited models and/or data are available to represent the broader distribution system.

The following sections provide greater detail on each of the methods listed including common misconceptions, advantages, disadvantages, and recommendations. The information provided within this report is the based upon available information at the time of publication. Methods are evolving rapidly and this should be taken into consideration throughout the report.

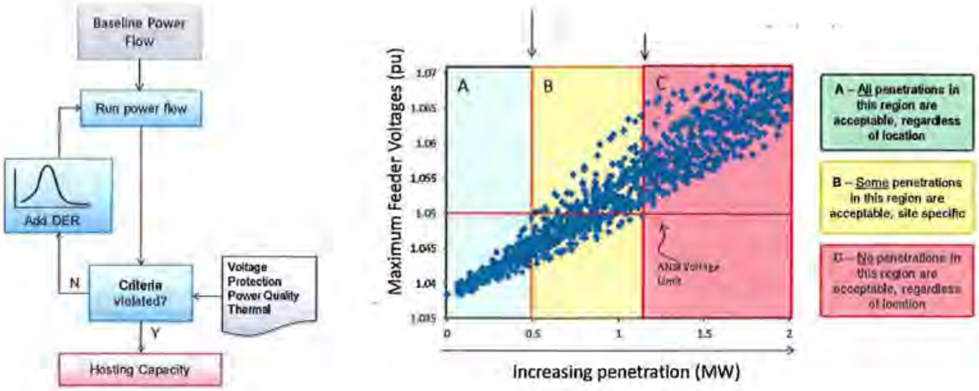
Stochastic Method

Overview

The first hosting capacity method developed and used in the industry that captured many of the grid-related impact factors previously mentioned was referred to as a stochastic-based approach[8]. This approach essentially starts by performing a baseline power flow analysis and increases DER penetration throughout the feeder using various sizes and locations to simulate 1000's of scenarios and extract the range of impacts conceivable for future DER deployments. Larger, three-phase systems can be analyzed as well as behind-the-meter DER systems.

The premise is that each DER system is modeled explicitly and detailed power flow and fault flow simulations are executed within the distribution modeling software to examine impacts. This is performed each time the DER penetration and/or location is changed. These power flow and fault flow solutions are simultaneously compared to baseline and user defined thresholds on each iteration. Hosting capacity is determined when DER impacts exceed the user defined thresholds. A flow chart and illustration of this process is shown in Figure 3-1.

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



Simplified Diagram

Example Output

Figure 3-1
Simplified Diagram and Example Output Depicting Stochastic-Based Approach

Common Misconceptions

One misconception about the stochastic method is that it is the same as a detailed study and therefore can be used for interconnection. In utilizing this method, EPRI found that in fact it does not capture the full range of DER impacts as a detailed study because DER is not examined at one location at a time. In a stochastic analysis, DER is added at multiple locations across the feeder representing a future planning scenario when there could be a distribution of DER on the feeder.

Assumptions

A number of assumptions are made within the method and the below list attempts to capture those pertinent to hosting capacity results. As methods continue to evolve over time so will the associated assumptions. Although power flow and fault flows are an integral part of this method, assumptions are made that will result in an estimate of hosting capacity.

- All distribution planning tool vendors will implement the stochastic approach the same way. Based upon EPRI's experience, this can be rather challenging to do and would therefore need to be verified through extensive comparative analysis.
- All DER locations are examined. This is typically not the case as the user tends to define the number of scenarios and/or locations to consider in the analysis. Typical selections available include load location, any location, or limited to specific locations such as three-phase nodes only.
- All DER sizes are considered. This is typically not the case as the user tends to define the size of each individual DER. This could be based on load sizes, a user-defined size, or any random size.
- All DER has the same characteristics. This is typically not the case as the user tends to define the DER to model in the analysis. PV, Wind, Synchronous, etc. have a range of characteristics such as output variability and fault current.

Implementations

The stochastic-based hosting capacity was originally developed in OpenDSS through various industry-wide research projects[9] and subsequently implemented similarly in the Distribution Engineering Workstation for Pepco Holdings.[10] These analyses have also been adopted in other distribution software tools such as Synergi Electric. The stochastic-based hosting capacity method is not solely independent of other methods. The stochastic method is only differentiated based on examining a distribution of DER, thus future implementation can be combined with other methods. The descriptions and comparisons made throughout this report are based upon the original OpenDSS implementation.

Data Input, Storage, and Computational Requirements

Table 3-1 provides an overview of the stochastic method and certain parameters, including input data, storage, and computation times. The total simulation time per feeder depends on the number of stochastic scenarios considered. Considering two load levels, one DER type, and 1000 stochastic location-based DER scenarios, examined with full power flow and fault flow simulations, takes approximately 20 hours to analyze. This time is further driven by many factors including complexity of the circuit models and computational resources.

Table 3-1
Requirements for Stochastic Method

Requirement	
Input Data	• Feeder circuit models
	• Two load levels
	• One DER type
	• 1000 load-based DER scenarios
Data Storage	• ~ 1.0 GB/feeder (varies based upon feeder and implementation)
Computational Times	• ~ 20 hours (varies based upon feeder and implementation)

Advantages

- *Educating the industry.* This method is easily understandable and valuable in educating the industry on the impacts of DER as it relates to size and location.
- *Effectively identifies "range" of impacts at future penetration levels.* From a research standpoint, this method is valuable in calculating the range of possible impacts due to DER locations and sizes that could exist at future penetration levels.

[9] *Distributed Photovoltaic Feeder Analysis: Preliminary Findings from Hosting Capacity Analysis of 18 Distribution Feeders*. EPRI, Palo Alto, CA: 2013. 3002001245.

[10] Steffel, S. "Model-Based Integrated High Penetration Renewables Planning and Control Analysis," Award # DE-EE0006328, December 2017

Disadvantages

- *Time and data intensive.* This approach is extremely time-consuming as well as data and computationally intensive.
- *Not effective at capturing full range of distributed DER impacts (locations).* Even with the large number of DER scenarios considered, EPRI found that it doesn't capture the full range of DER location-based scenarios. More cases could be considered such as locations and sizes of individual DERs, but at the expense of significant increases in data and time.
- *Applicable to specific impact factors only.* Sensitivity cases are executed based on the impact factors, however, each one of these scenario cases doubled the work effort and are used in select conditions/studies only.
- *Difficult to consider range of possible DER and grid scenarios.* The random nature of the deployments, including all locations (three-phase and single-phase), feeder reconfigurations, and DER types, etc., is extremely difficult to capture.

Recommendations

The stochastic-based method is valuable and necessary when planning for future DER scenarios, but the method does not provide guidance to DER developers or utility engineers on location-specific DER impacts. The detailed implementation of the method is not easily repeated or replicated across entire distribution systems. This method is not practically scalable from a planning standpoint where 100's to 1000's of feeders may need to be simulated. In order to minimize the data and resource burden, one typically has to limit the cases, locations, and scenarios considered. Even under such circumstances, the analysis can require hours to days to simulate a single feeder.

This is an effective method to be used as a research tool, but it is not recommended for broad application beyond that. EPRI continues to utilize this approach for select R&D projects where direct modeling of DER is needed on only select feeders. Aspects of this approach are valuable when implemented in other methods to consider impacts for DER planning.

Streamlined ICA Method

Overview

In response to the California Legislature Assembly Bill 327, PUC Section 769, PG&E submitted their Distribution Resource Plan (DRP) that encompasses, among other items, an Integration Capacity Analysis (ICA) to determine hosting capacity. PG&E's approach was a streamlined ICA method[11] that calculates hosting capacity across a distribution system, capturing the grid and DER specific impact factors. The streamlined method was developed recognizing that direct-modeling of all the DER scenarios would require extensive resources and simulation time.

The method applies a set of equations and algorithms to evaluate power system criteria at each node on the distribution system. This method performs analysis in an efficient streamlined

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

approach[12] that does not require directly modeling DER in a power system tool to observe impact. By not relying on direct modeling and simulation of DER, system wide scenario analysis can be conducted with much less processing requirements. Details regarding the equations used within this streamlined method are described fully in PG&E's DEMO A/B report.[13]

As shown in Figure 3-2, the streamlined method first performs a baseline power flow simulation to acquire the initial conditions of the circuit that will be used in the streamlined calculations. These conditions, for example, include electrical characteristics such as thermal ratings, resistance, voltages, currents, and fault duties. The streamlined method then evaluates the power system criteria, including thermal, voltage, protection, and safety limits independently to determine the hosting capacity at a given node or component on the system. The equations are implemented within a database that enables fast computations on large datasets.

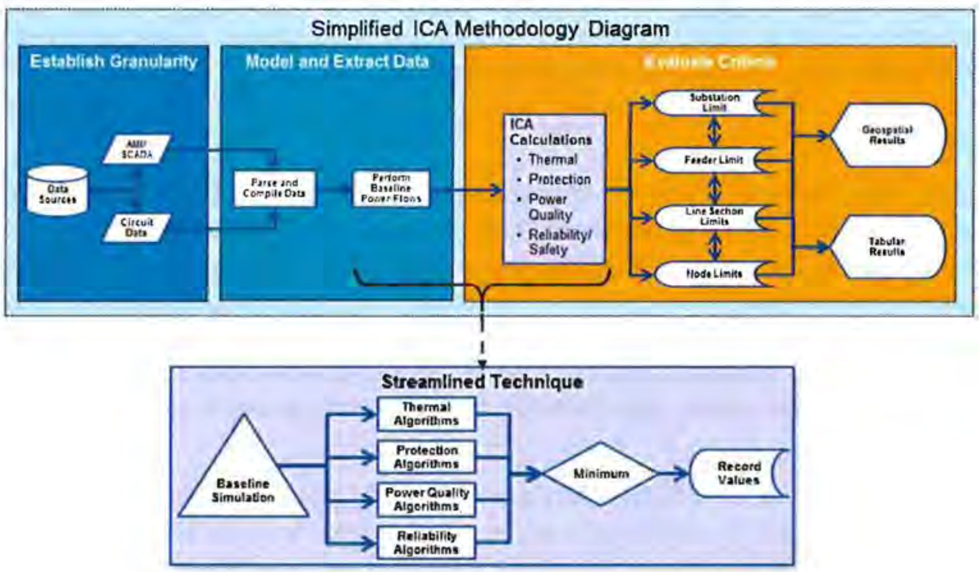


Figure 3-2
Simplified Diagram of PG&E's Streamlined Method

As part of the California ICA requirements, this process is repeated for multiple time periods (576 representative hours) to try and 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:

---

[12] A common misconception is that of the PG&E and EPRI methods being one in the same. Both methods are similar in concept, however the actual algorithms are different and direct comparative analyses have not been performed to date.

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

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.

Another important step in the ICA process is the concept of layered abstraction. 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.

The process of evaluation can be seen across the criteria at each layer as illustrated in Figure 3-3. This approach is important to obtain specific 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.

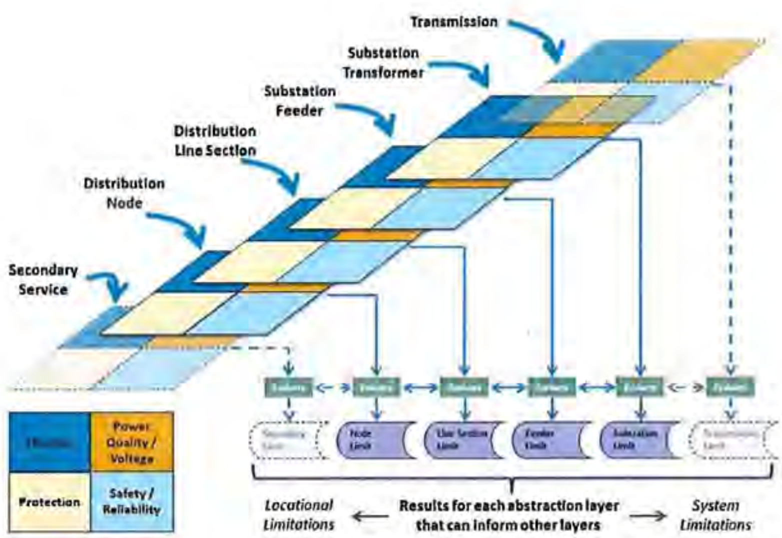
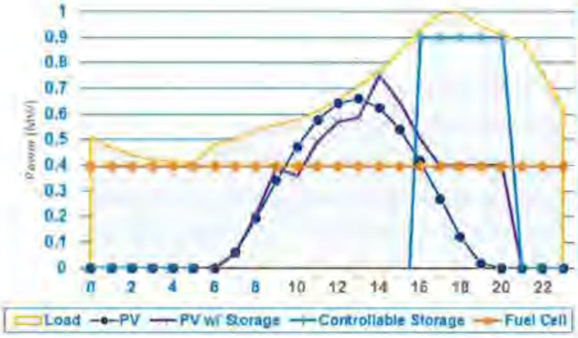


Figure 3-3
Illustration of Layered Abstraction Process

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

To determine DER technology-specific hosting capacity, assumed DER profiles of each technology are then compared to the agnostic hosting capacity results to derive technology-specific hosting capacity values as shown in Figure 3-4. This analysis can be performed separate from the underlying simulation framework, thus allowing flexibility in evaluating different DER technologies and combinations. Slight variations in load and/or assumed DER profiles used in the underlying 576 time-point analysis can significantly increase or decrease this final DER technology-specific hosting capacity. *This concern will be expanded upon in a follow-up white paper.*



DER	Limiting Hour	Max Capacity
PV	12 PM	0.66 MW
PV w/ Storage	2 PM	0.75 MW
Controllable Storage	4 PM	0.90 MW
Fuel Cell	6 AM	0.40 MW

Figure 3-4
DER Hosting Capacity Limits Assuming DER Profile Shapes

Common Misconceptions

One misconception regarding the streamlined method is that it and the EPRI DRIVE method are the same. While originally developed under a similar premise, these methods have diverged and are in fact different and employ a different approach and different algorithms. If given the chance for the Streamlined ICA method to mature and be further developed, these methods would likely have converged. Another misconception is that the streamlined method is a "simplified" approach to calculating hosting capacity. In reality, this method is more complex than other approaches like iterative.

Assumptions

A number of assumptions are made within the 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. Note, any assumption made will result in an estimate of hosting capacity.

- Equations and algorithms can effectively account for the dynamics of the distribution system.
- Existing DER does not contribute to voltage deviation. For example, voltage deviation calculations assume all existing DER has a fixed output and does not contribute to voltage changes. In some cases, this can overestimate hosting capacity.
- Agnostic (non-specific DER) hosting capacity is determined. This implies that the hosting capacity of specific DER types can be extrapolated from the results.
- DER profiles are assumed for each technology. Variations in the profiles used in the 576 time points are likely to impact the agnostic (non-specific DER) hosting capacity.
- Time-series analysis is performed to derive the time-based hosting capacity. The 576 load points used to create the time-series analysis is based on a discontinuous set of data as high load days do not transition directly into the low load days of each month. Voltage control from one day would not necessarily be the correct voltage control for the transition to the following day. *This concern will be expanded upon in a follow-up white paper.*

Implementations

PG&E's streamlined hosting capacity method was developed within the CYME platform leveraging python scripting and SQL databases.

Data Input, Storage, and Computational Requirements

Table 3-2 provides an overview of the streamlined ICA method and certain parameters, including input data, storage, and computation times. The total simulation time per feeder ranges from 2-30 minutes, with times being driven by many factors including complexity of the circuit models and computational resources.

Table 3-2
Requirements for Streamlined ICA Method

Requirement	
Input Data	• Feeder circuit models
	• 576 load levels derived from Smart Meter data
Data Storage	• ~ 15 MB/feeder (varies based upon feeder and implementation)
Computational Times	• SCE: 2 minutes/feeder
	• PGE: <10 minutes/feeder
	• SDG&E: 30 minutes/feeder

Advantages

- *Computational efficiency.* The ability to utilize equations and algorithms within a database enables faster computation of large datasets.
- *Time-based hosting capacity.* Provides insight to how hosting capacity changes over time and the ability to derive a hosting capacity portfolio based on DER profiles.
- *Potential for scenario analysis.* Due to the computation efficiency, "what-if" scenarios such as DER forecasts, reconfiguration, smart inverter settings, DER mitigation strategies, etc. can easily be considered.
- *Solution convergence.* If the baseline power flows solve correctly, the method does not have non-convergence issues.

Disadvantages

- *Not well understood by all stakeholders.* The approach used is a new technique and not easily understood by all stakeholders.
- *Accuracy.* Methods utilized in the streamlined approach may not capture some of the dynamic effects on more complex circuits
- *Single site DER only.* This analysis considers single site DER and does not currently consider the aggregate impacts of distributed DER (e.g., rooftop PV) needed when planning for future DER scenarios.

- *Uses non-standard distribution modeling data.* This approach requires smart meter data and other sources to derive granular time-series load and DER forecast data at the node/section level for each distribution feeder (576 hour profiles).

Recommendations

Providing efficient methods to assess hosting capacity is the recommended approach for addressing many of the modeling and simulation challenges today. Developing agnostic hosting capacity results is a unique aspect of the ICA approach that enables the rigorous hosting capacity assessments to be performed upfront while allowing the actual DER-specific results to then be derived offline, but the process needs further validation.

The streamlined approach can easily be applied to multiple time periods to derive a time-based hosting capacity. This is also a novel and efficient method for enabling various DER portfolio mixes to be considered in a scenario-type analysis that is extremely beneficial (e.g., planning). However, further consideration should be given to the impact of the 576 hour input load forecasts on the time-based hosting capacity results. Slight variations in the shape of the load (and existing DER) forecast can significantly impact DER-specific hosting capacities where DER profiles are "fitted" to the hosting capacity curves at each hour. As such, further sensitivity analysis should be done to evaluate likely impacts of small variations in load and DER profile assumptions. Also further assessments should be completed of the input time-series data and validate simulation results through actual field verification.

Finally, the streamlined method results should be compared with results from other methods to gain confidence in the accuracy.

Iterative ICA Method

Overview

Similar to PG&E, SCE and SDG&E responded to AB 327 with their own hosting capacity approach, the iterative Integration Capacity Analysis (ICA) method. In contrast to the streamlined ICA method, the iterative ICA approach[14,15] leverages distribution planning tools such as CYME and Synergi to perform the voltage and thermal impact assessments rather than utilizing a calculation-based approach. This is a technique somewhat similar to the stochastic method listed previously. However, the difference in this method is that single locations are considered one at a time with DER modeled, while the DER capacity is increased until issues occur on the system. This method is also somewhat similar to the streamlined ICA method in that the analysis iterates through 576 load conditions with layered abstraction of agnostic hosting capacity results and assumed DER profiles for post-analysis.

As shown in Figure 3-5, the iterative method essentially increases the DER at each node until a violation occurs. Locations are analyzed independently with power flow simulations performed

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

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

to determine the maximum level of DER that can interconnect at these locations without exceeding thermal and voltage limits.

In addition to the power flow simulations, which are used primarily to evaluate thermal and steady state voltage conditions, a protection analysis is also performed 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.

Due to the more significant demand on the distribution software tool, the iterative analysis can result in long processing times, especially when expanded to large numbers of distribution feeders or when the feeders themselves are more complex. However, the iterative method **attempts** to parallel the California IOUs' interconnection studies that are performed as part of a detailed interconnection study process.

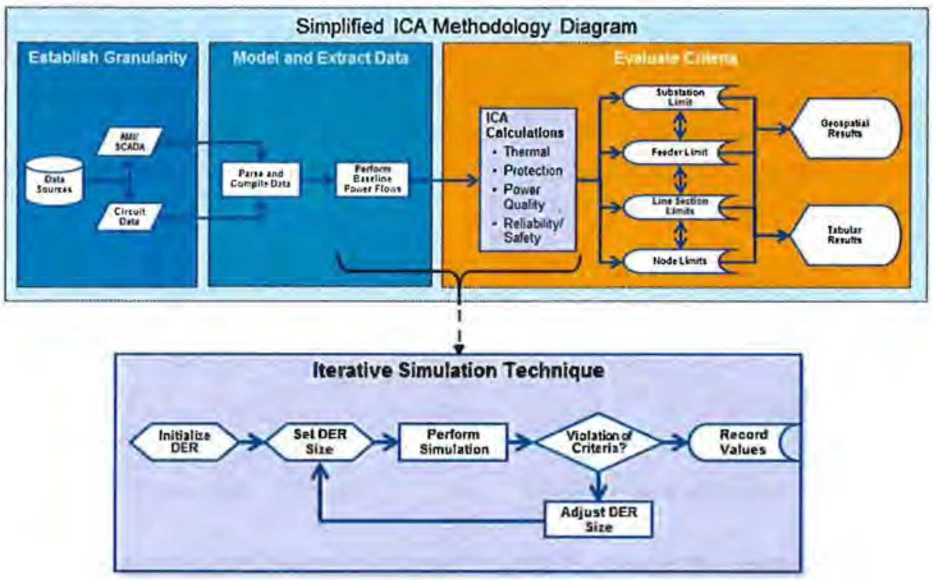


Figure 3-5
Simplified Diagram of SCE/SDG&E's Iterative Method

Common Misconceptions

There are some common misconceptions surrounding the iterative analysis that are important to understand as well. First, that the iterative method is the same as a detailed study in that power flow and fault flow analyses are performed for each iteration of DER and can therefore be used in the place of an interconnection study. However, results seem to indicate[16] this is not the case. To achieve simulation speeds needed to run 576 load levels (effectively repeating the feeder hosting capacity analysis 576 separate times), more efficient routines were used. In the current form of the iterative ICA analysis, one example is that protection-based hosting capacities are solved without an iterative approach. Detailed hosting capacity assessments of protection issues

[16] EPIC 1 – Project 4 Demonstration of Grid Support Functions of Distributed Energy Resources ("DER"): Demonstration and Comparison of the "EPRI Distribution Resource Integration and Value Estimation Hosting Capacity" and "SDG&E Iterative Integration Capacity Analysis" Tools, to be published Dec. 2017

as performed previously in OpenDSS[17] are much more complicated than examining voltage and thermal concerns. This in turn leads protection issues to be determined through means other than an iterative fault flow analysis.

Another misconception is that iterative ICA implementation across different software vendors will be consistent. Based on the vendor's extensive knowledge around model analysis and simulation performance, implementation will vary and could consist of alternative routines for performance and accuracy. One possible example of this is in how each tool develops applications for a faster load-flow analysis. Model reduction routines or simplifications have been found to work well, however, they may be done differently and result in streamlined assumptions. Another possible example involves expediting the process using "search and find" routines to determine the hosting capacity result rather than incrementally stepping through DER penetration levels.

To further the point on varying implementation, the iterative method has been utilized by all three IOU's, SCE (CYME), SDG&E (Synergi), and PG&E (CYME) as part of the CA DRP DEMO A/B projects. Below is a sample comparing the iterative approach tested on the same feeder, but conducted by the different utilities and their respective software platforms. Figure 3-6 illustrates the actual short-circuit impedance and voltage profile differences using the two different power flow tools (CYME and Synergi).

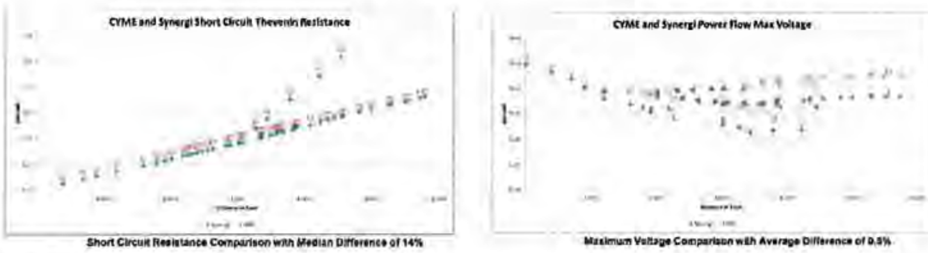
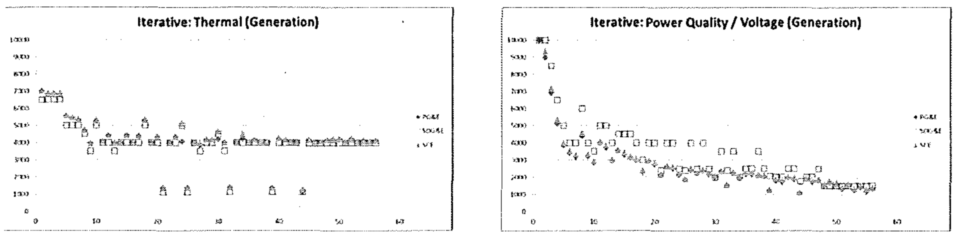


Figure 3-6
Sample Plots Illustrating Differences in Short-Circuit and Power Flow Results (CYME/Synergi)[18]

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

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

Figure 3-7 illustrates the actual hosting capacity results from the iterative method, but conducted by each IOU separately. Results indicate the thermal-based hosting capacity assessments are very similar, while the voltage-based hosting capacity varies considerably (in some cases up to 1.5 MW). These differences can be attributed to underlying differences in the power flow results as well as the actual method implementation in the separate tools.



Iterative Thermal IC Comparison **Iterative PQ IC Comparison**

Figure 3-7
Sample Results Comparing the Iterative Method Implemented by PG&E (CYME), SDG&E (Synergi), and SCE (CYME)[18]

Further analysis would likely indicate the root cause of the differences; however, these results do provide valuable information as it relates to illustrating the importance of hosting capacity impact factors outside of the method utilized. Specifically,

- minor variations in vendor implementation can change hosting capacity outcomes, and
- differences in modeling the same feeders using normal modeling practices can vary and therefore result in different hosting capacity values.

These are important when considering implementation of a method for various applications.

Assumptions

A number of assumptions are made within the method and the below list attempts to capture some of those pertinent to hosting capacity results. As methods continue to evolve over time so will the associated assumptions. Note, any assumption made will result in an estimate of hosting capacity.

- All distribution planning tool vendors will implement the iterative approach the same way.
- Existing DER does not contribute to voltage deviation. For example, voltage deviation calculations assume all existing DER has a fixed output and does not contribute to voltage changes. In some cases, this can overestimate hosting capacity.
- Agnostic (non-specific DER) hosting capacity is determined. This implies that the hosting capacity of specific DER types can be extrapolated to create a portfolio.
- DER profiles are assumed for each technology. Variations in the profiles used in the 576 time points are likely to impact the agnostic hosting capacity.

- Voltage regulation (LTC, line regulator, capacitor) is allowed to operate to adjust for DER impacts.[19]

Implementations

The iterative ICA analysis leverages results from vendor tools along with in-house methods. Vendor tools such as CYME and Synergi have implemented their own proprietary iterative hosting capacity methods. These methods provide the voltage and thermal hosting capacity results, while the in-house methods are used in conjunction with the vendor tools to provide additional results and pull together all the information required for the ICA analysis.

Data Input, Storage, and Computational Requirements

Table 3-3 provides an overview of the iterative ICA method and certain parameters, including input data, storage, and computation times. The total simulation time per feeder ranges from 0.5 hours to 27 hours, with times being driven by many factors including complexity of the circuit models and computational resources.

Table 3-3
Requirements for Iterative ICA Method

Requirement	
Input Data	• Feeder circuit models
	• 576 hourly load profiles derived from Smart Meter data
Data Storage	• ~ 15 MB/feeder
Computational Times	• SCE: 0.5 hours/feeder
	• PGE: 1 hour/feeder
	• SDG&E: 27 hours/feeder

Advantages

- *Similar in concept to interconnection studies.* This method is similar in concept to what is performed when executing an interconnection study where the distribution planning software is leveraged to determine DER impact.
- *Uses readily available planning tools.* This approach does not require new algorithms to calculate hosting capacity, since the results are based on the standard load flow and fault flow engines.
- *Multiple platforms.* Methods have been implemented within both CYME and Synergi platforms.
- *Multi-feeder analysis.* The method can analyze all feeders into a substation simultaneously with the intent of capturing the aggregate impact to parallel feeders.

[19] 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.

- *Effective for single DER location analysis.* This approach can be rather effective when analyzing single locations of DER.
- *Time-based hosting capacity.* Provides insight to how hosting capacity changes over time and the ability to derive a hosting capacity portfolio.

Disadvantages

- *False sense of accuracy.* While this method is similar in concept to what is performed in an interconnection study, it is not as accurate as a detailed study. In an interconnection study the analysis focuses on the specifics of the application at hand thus allowing the engineer to consider a range of other impact factors that affect hosting capacity at that location. This is in stark contrast to hosting capacity methods that analyze the "breadth" of distribution systems (1000's of feeders), wherein assumptions are made that do not capture the DER application-specific impacts factors that are considered in detailed interconnection studies.
- *Time and data intensive.* Similar to the stochastic-based approach, this effort requires significant time, data, and computational cycles to complete.
- *Uses non-standard distribution modeling data.* This approach requires smart meter data and other sources to derive granular time-series load and DER forecast data at the node/section level for each distribution feeder (576 hour profiles).
- *Single site DER only.* This analysis considers single site DER and does not currently consider the aggregate impacts of distributed DER (e.g., rooftop PV) needed when planning for future DER scenarios. This will likely change as the method further evolves.
- *DER agnostic hosting capacity.* The iterative power flow solution's hosting capacity is derived irrespective of DER technology but depending upon how a specific type of DER interacts with the grid (solar, wind, storage, CHP, etc.) the hosting capacity can change. In some cases, this may require additional iterations and solutions to be performed.
- *Limited scenario analysis capability.* Due to the computation burden to analyze systems as is, actual "what-if" scenarios such as DER forecasts, reconfiguration, smart inverter settings, DER mitigation strategies, etc. is limited.
- *Solution issues when analyzing additional time periods.* It is not uncommon to encounter bad data when attempting to create models for different time periods. EPRI has found, through extensive DER modeling, missing or "bad data" can cause simulations to provide undesirable outcomes.[20]

Recommendations

Based on the time and intensity to perform the iterative ICA analysis, this method is not practically scalable from a planning standpoint where 100's to 1000's of feeders may need to be simulated along with additional impact factors and updated on a regular basis. In order to minimize the data and resource burden, one typically has to limit the cases, locations, and scenarios considered or make the analysis more efficient. For the sake of efficiency, this has already been observed in the application of the CA iterative ICA analysis where there appear to

[20] Note this was an issue also identified by PG&E during the ICA process.

be components of streamlined methods employed. EPRI recommends implementing such hybrid techniques.

Developing an agnostic hosting capacity result is a unique aspect of the ICA approach that enables the rigorous hosting capacity assessments to be performed upfront while allowing the actual DER-specific results to then be derived offline. However, the process needs further validation.

Further consideration should also be given to the impact of the 576 hour input load forecasts on the time-based hosting capacity results. Further sensitivity analysis should be done to evaluate likely impacts of small variations in load and DER profile assumptions. Further assessments of the input time-series data and validate simulation results through actual field verification is also recommended.

Due to the computational burden of the 576 hour simulations at each node on each feeder, this type of direct DER modeling for time-based hosting capacity should be reserved for analysis of select feeders and locations where 1) simulation timesteps can be reduced to capture control interactions, and 2) multiple impact factors can be considered.

One of the advantages of performing time series analysis is that it can quantify the impact various conditions (DER) has on control interactions. Because this approach is focused on hourly-resolution simulations, the control interactions are not actually being captured in the analysis. Further analysis should be done to look at the impact of considering hourly resolution timestep versus a more granular timestep appropriate for capturing control interaction (5-30 seconds).

DRIVE (Hybrid) Method

The Distribution Resource Integration and Value Estimation (DRIVE) hosting capacity method is the successor to the stochastic and detailed methods previously developed by EPRI. DRIVE was developed to overcome the computation burden but still capture critical grid responses for determining location-based hosting capacity.

Initially developed as a PV hosting capacity method,[21] this method was 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 active/reactive output variability. The specific DER technology determines how the analysis is setup to properly quantify the unique impacts of the particular resource. The DRIVE method does not provide an agnostic hosting capacity, but rather a hosting capacity for the resource characteristics being considered.

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.[22]

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

[22] *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.

Overview

The original method behind the DRIVE tool was similar in concept to the streamlined method developed by PG&E where a select number of power flow cases are used to characterize the feeder response, then calculations are performed to determine DER scenario impacts and hosting capacities. However, the current underlying approach and equations are different.[23] DRIVE is also similar to the iterative ICA method in that the tool has employed ways to make the analysis more efficient, i.e., protection analysis. The DRIVE analysis has also evolved through extensive detailed studies and continues to evolve in the same manner. In practice, the DRIVE approach has been shown to take a streamlined approach, while still achieving results similar to a detailed analysis.

There are two components in the DRIVE tool as shown in Figure 3-8. 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[24] but is undergoing further modification.

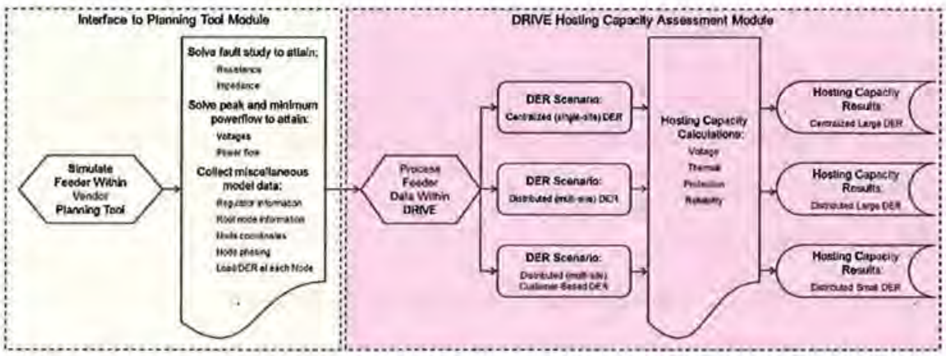


Figure 3-8
Components of DRIVE

Interface to Planning Tool Module

The interface to the planning tool 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. The 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. This ability is currently being expanded to provide a time-based hosting capacity similar to the requirements of ICA.

[23] Direct comparison of results from the two methods has not been performed.

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

The initial power flows are also conducted with existing DER disabled. 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.

Hosting Capacity Assessment

The DER assessments are then performed by applying various DER "scenarios" based on current injection. The hosting capacity is determined based on whether the specific scenario exceeds a user-defined threshold for voltage, thermal, and protection issues.[25] The DER scenarios analyzed consider centralized (single-site) and distributed (multiple-site) DER locations. Each scenario results in a unique hosting capacity value and therefore there is a range in hosting capacities for the feeder. The DER scenarios include the 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 3-9. 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.

[25] Equations detailing the evaluation the hosting capacity metrics can be found in *Distribution Planning with DER: System-Wide Assessment*. EPRI, Palo Alto, CA: 2017. 3002010356.

Figure 3-9
Simplistic Illustration of Centralized DER Analysis

Distributed (multi-site) DER: The hosting capacity scenario depicts how much distributed DER can be accommodated. The distribution of DER is based on three-phase nodes of the feeder. As shown in Figure 3-10, an incremental amount of DER is considered at each selected node. This analysis provides insight to the feeder's ability to accommodate various deployments of multi-site DER.

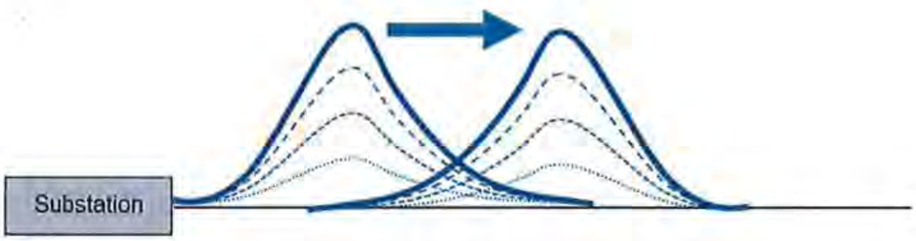


Figure 3-10
Simplistic Illustration of Distributed DER Analysis

Distributed (multi-site) Customer-Based DER: The hosting capacity scenario depicts how much distributed customer-based DER can be accommodated. The DER distribution is based on the location of existing customers and load on the feeder.

Common Misconceptions

A common misconception is that DRIVE and the PG&E streamlined method are the same. As previously mentioned, while the theory was initially similar, the underlying equations and approach have become very different. In short, these are two separate and unique methods. Another misconception is that DRIVE does not calculate hosting capacity for each node on every feeder. DRIVE is in fact capable of these granular calculations while also looking at the breadth of the system. Similarly, it is thought that DRIVE is limited in the hourly simulations that can be performed. In fact, DRIVE can be set up to run any number of hourly simulations.

It is also a misconception that DRIVE is not suited for informing interconnection applications as compared to the iterative method. Recent analysis has shown that the results of both methods are very similar.[26] DRIVE results can be used to inform interconnection screening just as any other hosting capacity method.

Assumptions

A number of assumptions are made within the 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. Note, any assumption made will result in an estimate of hosting capacity.

- DER is considered as a constant current injection. This implies DER current does not change during DER induced voltage rise and that fault currents in the protection analysis are independent of the impedance to the fault.
- Load magnitude does not change. When DER raises voltage during the hosting capacity assessment, loads remain constant.
- Voltage regulation equipment does not operate after the initial power flow studies are solved. Allowing voltage regulation equipment to operate during the hosting capacity analysis 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 the DRIVE algorithm that calculates the baseline hosting capacity before mitigation solutions are assessed.[27]
- When examining the impacts of existing DER, that DER is considered in every hosting capacity metric.

Implementations

The DRIVE methodology has currently been implemented to be compatible with the following software platforms: CYME, Synergi, Milsoft, OpenDSS, Gridlab-D, DEW, PVL, and PowerFactory. The methodology is also integrated into CYME as a new planning module.

Further implementation and enhancements are being developed through ongoing EPRI R&D and the dedicated DRIVE User Group (over 27 US and International utility members).

[26] EPIC 1 – Project 4 Demonstration of Grid Support Functions of Distributed Energy Resources ("DER"): Demonstration and Comparison of the "EPRI Distribution Resource Integration and Value Estimation Hosting Capacity" and "SDG&E Iterative Integration Capacity Analysis" Tools, to be published Dec. 2017

[27] Careful consideration should be given to enabling voltage regulation to mitigate DER-induced voltage rise. This is worth further discussion and will be addressed in a subsequent white paper.

Data Input, Storage, and Computational Requirements

Table 3-4 provides an overview of the DRIVE method and certain parameters, including input data, storage, and computation times. The typical simulation time per feeder ranges depending on many factors including complexity of the circuit models and computational resources.

Table 3-4
Requirements for DRIVE Method

Requirement	
Input Data	• Feeder circuit models
	• Minimum of 2 loadflow cases
Data Storage	• ~ 1 MB per feeder
Computational Times	• ~ 5 minutes per feeder

Advantages

- *Hybrid Approach.* Built of learnings from all methods with roots in stochastic analysis, it now takes a streamlined approach while achieving an iterative result.
- *Multiple software platforms.* Currently compatible with CYME, Synergi, Milsoft, Powerfactory, OpenDSS, Gridlab-D, DEW, and PVL platforms.
- *Consistency.* Due to compatibility with the range of distribution planning platforms, a consistent approach can be applied across service territories where different planning tools are used.
- *Single-site and multi-site DER.* The method considers various DER scenarios that combine iterative (single-site DER) and stochastic (multiple-site DER) analyses.
- *Computational efficiency.* Hosting capacity for all scenarios calculated within minutes per feeder.
- *Potential for scenario analysis.* Due to the computation efficiency, "what-if" scenarios such as DER forecasts, reconfiguration, smart inverter settings, DER mitigation strategies, etc. can easily be considered.
- *Solution convergence.* If the baseline power flow solves correctly, the method does not have non-convergence issues.
- *Industry collaboration.* Developed with broad industry input over the course of 5 years including over 50 utilities, Department of Energy, California Public Utilities Commission, and New York State Energy Research & Development Authority. Through the international DRIVE User Group, industry-wide collaboration will further provide guidance on future revisions/updates.
- *Time-based hosting capacity.* Easily applicable to observe how hosting capacity changes over time and derive a hosting capacity portfolio.

Disadvantages

- *Not well understood by all stakeholders.* The approach used in this analysis is a new technique developed for distribution analysis and not easily understood by all stakeholders. Because of this, EPRI has published dozens of papers and participated/presented in multiple industry conferences and stakeholder processes to ensure transparency.
- *Different technique from interconnection studies.* The method used is different than that traditionally used for detailed interconnection studies. While this is the case, the results are still useful in informing interconnection processes.
- *DER Portfolios.* The present version does not enable consideration for portfolios of DER. The hosting capacity calculations are calculated based on specific DER characteristics.
- *Single-feeder analysis only.* The current method analyzes one feeder at a time. Aggregate impacts of parallel feeder DER are captured through aggregation techniques.[28] Substation impacts are not yet considered.

Recommendations

The goal of the DRIVE method is similar to that proposed by PG&E: develop and implement an effective means for assessing location-based impacts of DER that can consider both the breadth and depth of the system. This method has proven to be effective at providing a tool for such applications through the wide industry adoption of the technique.

The initial implementation, while effective, was found to provide conservative results in some cases. Further refinements have been made through ongoing R&D addressing these concerns. The current method strikes a balance between computational efficiency and method accuracy by leveraging lessons learned from EPRI's previously implemented iterative and stochastic-based methods. The present implementation utilizes "streamlined" methods but replicates "iterative" type results.[29] Refinements will continue to improve the overall method and expand the applications further. Since the method is not vendor specific, it also allows uniform analysis to be executed across different vendor tools and utility service territories.

As such, this method should be used when engineers need to efficiently identify the DER capacity that can be accommodated at the node/section level on distribution systems using their existing planning tools and data. Due to the computational efficiency, the method can be applied to evaluate various scenarios like grid conditions and smart inverter impacts.

It is also recommended that due to the need to address hosting capacity portfolios, the tool needs to evolve to consider time-based hosting capacity. Further consideration should also be given to enabling efficient execution of scenario analysis for batch mode processing.

[28] *Determining Substation-Level Impacts of Multi-Feeder DER Penetration.* EPRI, Palo Alto, CA: 2016. 3002008299.

[29] EPIC 1 – Project 4 Demonstration of Grid Support Functions of Distributed Energy Resources ("DER"): Demonstration and Comparison of the "EPRI Distribution Resource Integration and Value Estimation Hosting Capacity" and "SDG&E Iterative Integration Capacity Analysis" Tools, to be published Dec. 2017

Method Comparisons

The previous sections have given a fairly extensive view of each of the four methods. The following sections provide a high-level comparison of each.

Method Evaluation Criteria and DER Considerations

Distribution feeder evaluation criteria establish the metrics by which hosting capacity is derived. There exists commonality in evaluation criteria across the methods such that voltage, thermal, protection, and reliability are considered (see Table 3-5). However, there are differences depending on the way the hosting capacity metrics are derived. For example, one implementation of Iterative ICA derives hosting capacity for "voltage" which considers overvoltage or undervoltage criteria violations. Alternatively, DRIVE considers the "overvoltage" and "undervoltage" separately to derive two unique hosting capacity metrics.

Table 3-5
Evaluation Criteria Comparison

Category	Criteria	Stochastic	Iterative ICA	Streamlined ICA	DRIVE
Voltage	Primary Over-Voltage	Y	Y	Y	Y
	Primary Under-Voltage	Y	Y	Y	Y
	Primary Voltage Deviation	Y	Y	Y	Y
	Regulator Voltage Deviation	Y	N	N	Y
	Secondary Overvoltage	Y	N	N	N
Thermal	Charging DER (Demand)	N	Y	Y	Y
	Discharging DER(Generation)	Y	Y	Y	Y
Protection	Additional Element Fault Current	Y	Y	Y	Y
	Sympathetic Breaker Relay Tripping	Y	N	N	Y
	Breaker Relay Reduction of Reach	Y	Y	Y	Y
	Reverse Power Flow	Y	Y	Y	Y
	Unintentional Islanding	Y	Y	Y	Y

Likewise, each method addresses some of the same DER characteristics however there are gaps in some methods at present as shown in Table 3-6.

Table 3-6
DER Technology and Scenario Comparison

Category	Criteria	Stochastic	Iterative ICA	Streamlined ICA	DRIVE
DER Technologies	Solar	Y	Y	Y	Y
	Storage	N	Y	Y	Y
	Wind	N	Y	Y	Y
	Fuel Cell	N	Y	Y	Y
	Synchronous	N	Y	Y	Y
	DER Portfolios	N	Y	Y	N
DER Scenarios	Three-phase, single site	N	Y	Y	Y
	Three-phase, distributed	Y	N	N	Y
	Single-phase, single site	N	N	N	N
	Single-phase, distributed	Y	N	N	Y

Method Accuracy

There is a great deal of interest in the industry around method accuracies. In particular, some groups have questioned the accuracy of methods for hosting capacity.[30] As such, comparisons between methods have been performed in California as part of the Demo projects. This recent activity, while extremely valuable to the decision making in California has thus far been operating under the assumption that the iterative method produces accurate results and therefore establishes the known quantities for which other methods should be compared. When in fact, this may not be the case.

The accuracy of any method to true hosting capacity should be compared against results derived by considering all of the impact factors mentioned in Chapter 2, regardless of method. As noted previously, impact factors directly determine hosting capacity values and the more impact factors that can be considered the more accurate the outcome will be. The fewer impact factors that are considered the more of an approximation the result will be.

While it is clear that methods limiting the consideration of impact factors limit the ability to provide accurate hosting capacity values, it is important to understand that not all impact factors can be considered. The challenge is identifying the appropriate impact factors and innovating the

[30] Comments of the Interstate Renewable Energy Council, Inc. on the Supplemental Distributed System Implementation Plan. January 2017.

best methods and tools that can yield reasonable results without creating undue burden on data requirements, modeling implementations, and engineering time/resources. All four methods discussed in this report are currently undergoing this process.

As always, tradeoffs are made in any modeling and simulation exercise. Engineering judgment is necessary to determine 1) whether the appropriate factors are taken into account given the specific application and 2) the effectiveness (or lack thereof) of the underlying data and models in reflecting real world conditions. With any modeling and simulation effort, reasonable assumptions have to be made as a model that is 100% accurate is an unrealistic expectation.

Method Comparisons

Method comparisons thus far are not actually assessing accuracy, but rather testing how precise the methods are relative to each other in producing similar results. It is worth noting that a method can be extremely precise, while at the same time be inaccurate. Regardless, comparing the results of various methods as they evolve should be done. Using an IEEE test feeder is a suggested approach.

What follows is a summary of three recent comparison exercises. These exercises are useful in providing insights into how methods are being implemented, what impact factors are being considered, and how to improve all methods for greater confidence in results.

California IOU ICA Comparison of Iterative and Streamlined Analysis Results

As part of the California DRP Demo A efforts, the IOUs (SDG&E,[31] PG&E,[32] and SCE[33]) compared the results of the iterative method used by SDG&E and SCE and the streamlined method used by PG&E. It is worth noting that at the time of comparison, both methods were still in various stages of development. The iterative approach, being more commonly utilized, was further along in development, while the streamlined method, being relatively new, was further undergoing development as well as being refined.

In the reports filed by each utility, comparative graphics were included to illustrate the results of the analysis. Figure 3-11 below provides a summary of this comparison for thermal, voltage variation, and steady state voltage. The orange diamond points represent the results of the iterative analysis while the purple circle points represent the results of the streamlined analysis.

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

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

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

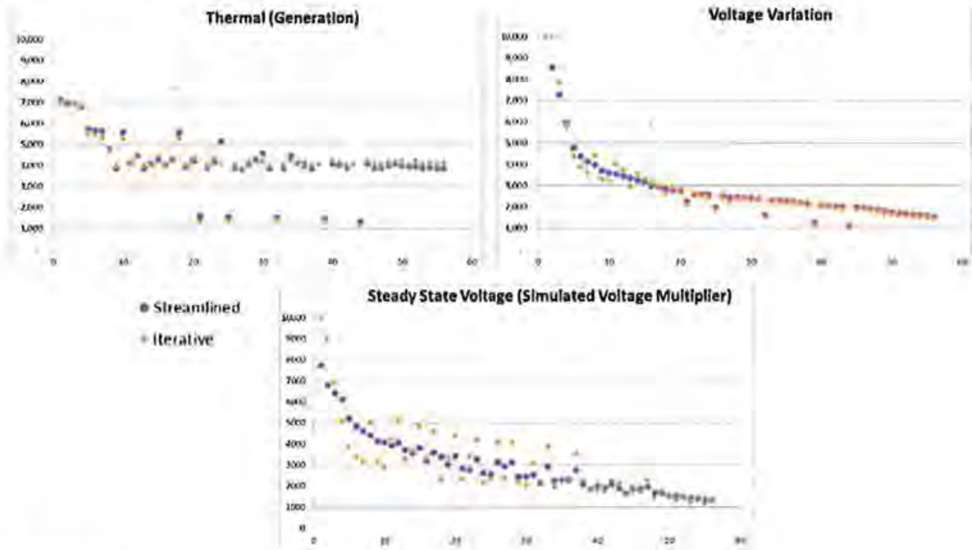


Figure 3-11
Results of ICA comparing iterative and streamlined methods

As can be seen in the figure, similar results were found across the iterative and streamlined approaches, but there were some variations noted in the steady state voltage analyses. Although not shown, variations were also noted in the protection analyses. Additionally, some variations were found to be a result of the software platforms being used by each utility as shown previously. Through the various comparisons made in the Demonstration A and B reports a number of items are worth noting provide some context into the results:

- The iterative method was implemented in two different software platforms yielding different results. This was due to how different vendors perform calculations.
- The streamlined method proposed by PG&E was implemented by SCE and SDG&E, with some variations found in implementation that also impacted results.

Differences in calculation *times* were another point of comparison. Even in the cases where the same method was used, calculation times varied considerably, with many factors contributing including circuit complexity, software platform, and computing power. The complete implementation of the CA ICA iterative analysis took an average of 27 hours per feeder. Note this time reflects running the iterative analysis for 576 time periods but does not reflect a detailed fault flow protection analysis. In comparison, the streamlined method took an average of 10 minutes per feeder.

Additionally, differences in calculation *precision* varied due to the consideration of a specific violation criteria. One example is that the thermal results comparing streamlined to iterative have a major difference in that the streamlined method did not consider fuse flow. Adding this violation to the streamlined method could result in closer values.

In the end, SDG&E and SCE converged on the concept that the iterative approach is more accurate (but time and data intensive) thus lending itself to application for interconnection studies, while PG&E took exception to this conclusion. PG&E concluded that that while the iterative approach is conceptually closer to a detailed interconnection study than that of streamlined, it practically falls short of truly mimicking the detailed analysis that would be performed as part of an interconnection study. All three utilities agreed the streamlined approach could be beneficial as a planning tool due to its ability to evaluate "what if" scenarios. The comparison efforts also uncovered computation issues and challenges in both methods. Some were rectified through the process while some require future attention.

Additionally, the findings in the report mentioned that the "initial evaluation of the demo circuit results for iterative (1) do not always provide an answer due to non-convergence in the power flow simulations and (2) had a huge sensitivity to other indirect conditions within the circuit." It was also noted that more work should be done to investigate discrepancies and refine the methods.

This comparison was only applied to the 123bus IEEE system. It is EPRI's experience that methods yield differing results on various feeders. Further comparison with a range of feeder types might yield additional findings on differences.

EPRI and SDG&E Comparison of DRIVE and Iterative ICA Analysis

Similar to the comparison done by the California IOUs, EPRI and SDG&E worked together on a comparison of the iterative ICA method to the EPRI DRIVE method. To do the comparison, SDG&E selected five feeders with a range of characteristics.

Figure 3-12 below provides a comparison of the hosting capacity results for a specific hour on one of the five feeders. The blue '+' points are the results of the iterative analysis while the red 'x' points are the results from the DRIVE analysis. The hosting capacity comparison is similar, but had some notable distinctions. Results seem to indicate the thermal discrepancy occurred in the iterative analysis because a detailed power flow may have not been executed for the location, but rather an alternative method was used to expedite the process. Further investigation regarding when/where alternative methods are used in the iterative method, have been suggested.

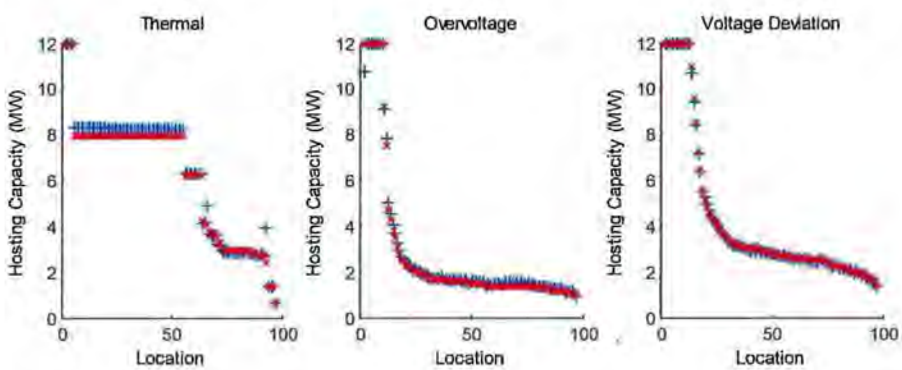


Figure 3-12
Hosting Capacity Comparison for Specific Hour (Blue +: Iterative Analysis, Red x: DRIVE Analysis)

Additional comparisons were made considering select single-hour analysis compared to the annual analysis from the Iterative ICA and the following findings were made:

1. **Different hosting capacity methods can provide similar results**: Hosting capacity results of the iterative method are in line with results of the DRIVE hosting capacity analysis. While there were some minor variations, 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:** 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 analysis. Specifically, this finding indicates that time and resources could be saved while achieving a similar result.
3. **Hosting capacity methods will continue to evolve and improve:** Hosting capacity methods will continue to evolve. Both methods are undergoing updates to improve precision and 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 them.

The recommendations and next steps as well as a full comparison is also publicly available.[34]

EPRI Validation of DRIVE with Detailed Analysis

A final example comparison is one performed by EPRI. In 2016, EPRI compared the results of the DRIVE method to that of an EPRI detailed hosting capacity analysis.[35] EPRI evaluated multiple feeders and specific locations to determine how the results may differ. Figure 3-13 below provides a summary of the results for thermal and overvoltage at several locations along 6 feeders. The results of the detailed analysis are shown in orange, while the results of the DRIVE analysis are shown in blue. The results are for DER at a specific location indicated by Lx.

[34] EPIC 1 – Project 4 Demonstration of Grid Support Functions of Distributed Energy Resources ("DER"): Demonstration and Comparison of the "EPRI Distribution Resource Integration and Value Estimation Hosting Capacity" and "SDG&E Iterative Integration Capacity Analysis" Tools, to be published Dec. 2017

[35] *Demonstration of Improved DER Screening through Hosting Capacity Method.* EPRI, Palo Alto, CA: 2016. 3002008294.

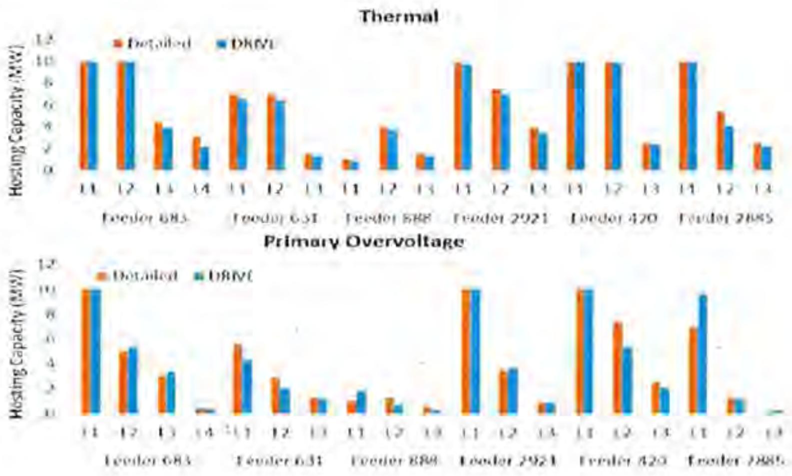


Figure 3-13
Thermal and overvoltage hosting capacity comparison for six feeders

As can be seen across the feeders in this example, the results of the DRIVE analysis are consistent with the detailed analysis for thermal. The outlier occurring for thermal on Feeder 2885 Location 2 was noted as a needed improvement to the DRIVE data extraction process from the base model. In the case of overvoltage, the largest mismatch occurs at the locations that have higher short circuit strength such as Feeder 2885 Location 1. For locations such as these, the impact from DER is relatively low as indicated by the higher hosting capacities. Other differences have been improved with refined DRIVE methods.

Flexibility

Hosting capacity is a foundational element that can be used to inform multiple applications, several of which have been discussed in this report. As the applications grow, however, the methods by which hosting capacity is calculated will need to evolve. Inevitably, the methods will become more complex, but at the same time, will be required to be more accurate, robust, and efficient.

To meet this need, the underlying methods must be flexible. For example, alternative approaches may be needed to account for distribution systems that have advanced controls such as distribution automation or smart inverters. Locking into one method without exploring alternative approaches will ultimately limit innovation in the future and may result in inaccurate or inefficient results. Without innovation, using today's methods to address evolving technologies and grid control/design changes in the future, would prove inadequate. In the same form, new applications for hosting capacity will require modifications to the underlying methodologies.

Consistency

Consistency is an important topic as it relates to having a common methodology applied across multiple vendor tools and utilities. As shown in the example of the iterative analysis producing different results from different vendor tools, the driving factor was most likely vendor implementation. Consistency among implementations is important, not only to get similar results, but also to allow the same quantities to be derived.

Consistency is more important for utilities that have different planning regions utilizing different software tools. The global planning process may require hosting capacity studies, but if the tools are different, the underlying studies might be inconsistent showing one region with a significantly different hosting capacity. The same can be said for states that are seeking a consistent hosting capacity method across a number of utilities, as is being done in NY and CA.

Computation Times

Due to the differences in the underlying computational solutions used within each method, wide variations in solution time are found, from a few minutes per feeder for Streamlined and DRIVE, all the way up to 27 hours per feeder for Iterative as shown in Table 3-7.

As further enhancements are made to each method it is expected computational efficiencies will be found, thus reducing simulation times. However, as additional scenarios are considered in the analysis (reconfiguration, smart inverter settings, etc.) the overall solution time will increase by a minimum factor of two. The number of load levels considered for each scenario will also considerably change the overall time for analysis. Currently, DRIVE and stochastic considers two load levels while iterative ICA and streamlined consider 576 load levels.

Table 3-7
Method Computational Time Comparison

Method	Computation Time
Stochastic	20 hours per feeder
Iterative	27 hours per feeder
Streamlined	10 minutes per feeder
DRIVE	5 minutes per feeder

EPRI Recommendation

Given these details about each of the hosting capacity methods, EPRI recommends the following:

1. **Methodology distinctions are just a label.** While this section outlines each of the four hosting capacity methods, a key point is that there is no clear distinction between these methods. Some stakeholders have indicated that lines can be drawn clearly putting each hosting method in a separate and unique box, however this is not the case. These labels are used as an attempt to differentiate methodologies, even though there is no clear scientific basis for, or justification and distinction between them. EPRI has found through extensive analysis that methods are adopting procedures used with many other methods and this is encouraging.
2. **Hosting capacity methods will continue to evolve and improve.** As demonstrated throughout this effort, hosting capacity methods will continue to evolve to improve precision. Likewise, 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. **Mandating how hosting capacity should be calculated sets the industry up for costly risks.** Mandating the mechanics of how hosting should be calculated is a risk and discourages innovation. Also, it does not leverage new analytics being developed within the industry to meet the growing needs and prohibits effective integration of emerging technologies. This risk has been observed already in California where the iterative approach was adopted, but operational flexibility calculations are having to rely on heuristics due to the computational intensity. The concern raised is that it may lead to unnecessarily limited hosting capacity in some cases.
4. **Comparison efforts thus far have been premature.** A great deal of work has been done to date in an attempt to compare the various methods however many of these comparisons were premature and limited in scope. For example, the comparative analysis performed in California evaluated two approaches (streamlined and iterative). The streamlined approach, which was new and still under development, was compared to that of iterative. While the iterative approach was more mature, it too was under development. Additionally, this comparative analysis did not consider further developed methods that were also available in the industry such as DRIVE. While this comparison was informative it was not comprehensive nor definitive. Given this example, work needs to be done to provide more comprehensive comparisons.
5. **Different hosting capacity methods can provide similar results.** EPRI has recently demonstrated, working with San Diego Gas & Electric to compare DRIVE to the Iterative ICA method, that different methods can in fact produce similar results. The hybrid DRIVE method was found to produce the same results as that found in the California Iterative ICA method. Based on this, there are opportunities for the industry to continue to refine and enhance multiple hosting capacity approaches while still achieving consistent results.

4
CONSIDERATIONS FOR HOSTING CAPACITY APPLICATIONS

Ideally, any hosting capacity methodology should be able to be utilized for all applications of its results. However, due to the lack of analyzed impact factors and the infancy of some methodologies, it is important to reemphasize what should be considered when using hosting capacity for particular applications.

Informing the Public

Utilizing hosting capacity calculations to generate heat maps of the distribution system gives developers 1) the ability to understand better/worse locations for DER on the system, 2) how those locations align with locations they have identified as well suited for DER installation, and 3) an initial indication of potential costs. Maps can be generated across the system, showing the minimum or maximum hosting capacity at the node, feeder, or substation level. Currently hosting capacity maps are being used in California, New York, and Minnesota. An example from an online portal is shown in Figure 4-1. These maps are not intended to act as a pre-screen or pre-approval for interconnection, but can help streamline the process by allowing developers to target more viable locations. However, doing so does present both opportunities and challenges that include the following list.

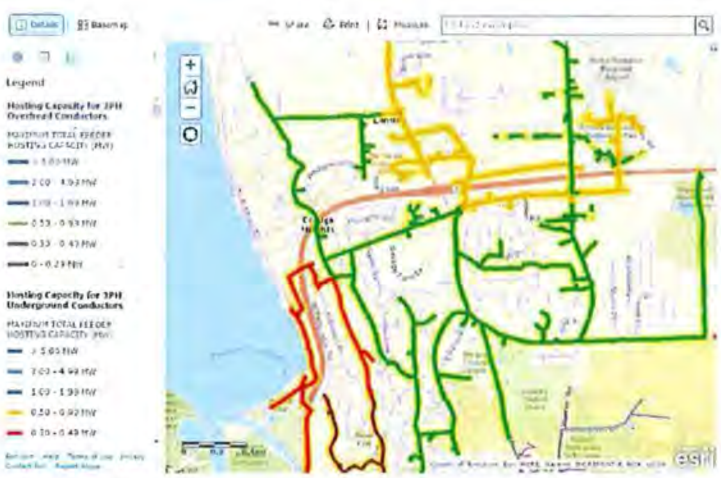


Figure 4-1
Informing the Public

What about pro-actively screening every location on a feeder?

Hosting capacity can be used to inform the locations that may be less suitable for DER, but should not be used to pre-screen every location or create a "click to claim" approach. This is not practical because each interconnection application is impacted by other interconnections in the queue. As DER penetration grows on a feeder, the hosting capacity changes and varies at each location along that feeder.

To accurately perform a technical review of a specific location, the impacts of other DER that are in the queue or on the feeder must be considered including size, type and location. These will have an impact on the overall ability of the system to host any new application. The challenge is that this is an ever-changing dataset and can only be considered at the time of an application submittal. Given this, attempting to pre-screen or even pre-study the system would not be effective.

- *Maps are intended to be a guide.* Hosting capacity values on a map should not be considered an approval for interconnection. The results are a snapshot in time and may not capture the latest grid or DER queue data. As such, maps should not be viewed as an automatic approval or means to remove the engineering judgment.
- *Maps can provide customers and developers with an indication of where higher-cost interconnection can be expected.* This can enable streamlined interconnection processes by minimizing the number of applications received that may require additional study by the utility thereby reducing the burden on utility engineers. In some cases, getting this indication rather than a hosting capacity value may be more useful.
- *Maps are a point-in-time representation of the hosting capacity.* While maps are informative, there are important limitations.
- *Applications in the queue.* Approved or installed DER may not be represented on a previously-developed map and could impact the remaining hosting capacity.
- *Grid updates.* Any change in utility operation on particular portions of the feeder may also change the hosting capacity. Due to the operational requirements of the distribution system and rate of application acceptance, the information provided is not real-time.
- *Maps should have established refresh rates.* Because of the constant change in the datasets being utilized and the use of maps, an appropriate refresh rate should be established for posting these maps. It is also important to weigh the costs and benefits associated with updating these maps regularly for both the utilities and developer communities. Defining this refresh rate and expectations is critical to preventing the potential to mis-inform the public.

With this in mind, there are important considerations in choosing the right hosting capacity method. These include the methods ability to provide:

- granularity of the calculations that capture hosting capacity at each location on the feeder
- speed with which updated results are attained
- scalability to look across the system
- visualization to easily export and view results
- sensitivity studies around important impact factors

Use of Hosting Capacity to Automate Technical Review

With recent efforts in many states to implement hosting capacity analysis, industry stakeholders are asking the question – should hosting capacity be used as an approach to automate interconnection screening?

Hosting capacity can inform this process, but should not be used to remove engineering judgement from the screening process. Hosting capacity can be used as the analytical calculation when doing a technical review on a specific application. In order to do so, the hosting capacity assessment should be focused on a single location to identify the specific limiting factor. This can be done by considering different sensitivities and identifying least-cost mitigation solutions needed to accommodate an interconnection. Evaluation should be informed by engineering judgement as well to ensure data and model validation is accurate. By reducing the dimensionality to a location, more specific impact factors can be considered. EPRI recommends sensitivity simulations around specific applications using baseline hosting capacity as a starting point.

Assisting with interconnection technical review

Typically, utilities follow several screening steps when reviewing an interconnection application. As shown in Figure 4-2, it includes fast track screens to evaluate first order technical concerns and geared at screening out smaller systems. The second step of screening, for those that fail fast track screens, is a supplemental review that looks more closely at technical issues and typically requires engineering judgement.

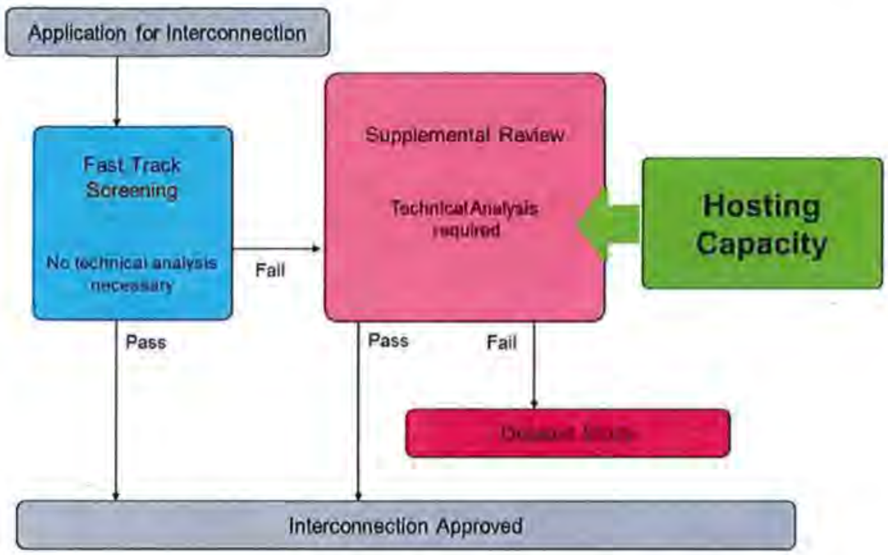


Figure 4-2
Assisting with Interconnection Technical Review

It is in this supplemental screening step that hosting capacity can inform the assessment made by the engineer. The hosting capacity calculations would provide information regarding the remaining amount of DER the feeder can host at a particular node and the limiting factor that may result in need for mitigation.

Similar in some ways to the opportunities and challenges related to mapping, there are important considerations for utilizing hosting capacity for interconnection review as well. While hosting capacity can act as an input for the technical review and the engineer's decision making, it should not be used as a solution to automate the technical review process. It is also important to weigh the costs and benefits associated with integrating the back office systems to handle this process with a constantly changing dataset.

Additionally, hosting capacity does not assess the characteristics of an individual interconnection that are submitted with the application (ranging from inverter certifications/control behaviors to site configuration). These aspects will become even more critical when smart inverters and energy storage systems are interconnecting. Finally, hosting capacity does not step through all of the screening procedures used to evaluate interconnections today, although some align and could provide input into that review.

With this in mind, there are important considerations in the hosting capacity method itself that must be evaluated:

- granularity of the calculations that capture hosting capacity at each location on the feeder
- scalability to look across the system
- frequency with which updated results are needed
- accuracy in considering important impact factors

Enabling Planning with DER

Hosting capacity analysis is a critical piece in the new distribution planning analytical framework. Figure 4-3 illustrates what a new planning process may look like with hosting capacity analysis informing multiple parts of the process including the long-term plan.

Figure 4-3
Enabling Planning with DER

Hosting capacity analysis becomes a metric to evaluate many forms of distribution analysis including: smart inverter settings, deployment scenarios, load/DER growth forecasts, assessment of new technology integration, planning for DMS, reliability assessments, distribution automation deployment, volt/var control schemes, etc. Using hosting capacity in the future enables utilities to look specifically at DERs impact and role in the planning process. Hosting capacity can provide the ability to look at a variety of scenarios and run sensitivities to inform decision making. However, as the distribution system becomes more complex, the number of what-if scenarios that needs to be evaluated will become too large to perform manually on a case by case basis. It is important to consider the need for automation to quickly move through a range of scenarios.

With this in mind, there are important considerations in the hosting capacity method itself that must be evaluated:

- scalability to look across the system
- sensitivity studies around important impact factors
- flexibility to consider different scenarios, DER technologies, and grid configurations

5
CONCLUSIONS

The industry's understanding and application of hosting capacity calculations have come a long way and will continue to be a vital piece of the approach when considering DER on the distribution system. This report outlines the important considerations when it comes to implementing a hosting capacity analysis for the purpose of informing interconnection, planning, and developers. Specific takeaways include:

1. **Comparison efforts thus far have been premature.** A great deal of work has been done to date in an attempt to compare the various methods however many of these comparisons were premature and limited in scope. For example, the comparative analysis performed in California evaluated two approaches (streamlined and iterative). The streamlined approach, which was new and still under development, was compared to that of iterative. While the iterative approach was more mature, it too was under development. Additionally, this comparative analysis did not consider further developed methods that were also available in the industry such as DRIVE. While this comparison was informative it was not comprehensive nor definitive. Given this example, work needs to be done to provide more comprehensive comparisons.
2. **Different hosting capacity methods can provide similar results.** EPRI has recently demonstrated, working with San Diego Gas & Electric to compare DRIVE to the Iterative ICA method, that different methods can in fact produce similar results. The hybrid DRIVE method was found to produce the same results as that found in the California Iterative ICA method. Based on this, there are opportunities for the industry to continue to refine and enhance multiple hosting capacity approaches while still achieving consistent results.
3. **Mandating how hosting capacity should be calculated sets the industry up for costly risks.** Mandating the mechanics of how hosting should be calculated is a risk and discourages innovation. Also, it does not leverage new analytics being developed within the industry to meet the growing needs and prohibits effective integration of emerging technologies. This risk has been observed already in California where the iterative approach was adopted, but operational flexibility calculations are having to rely on heuristics due to the computational intensity. The concern raised is that it may lead to unnecessarily limited hosting capacity in some cases.
4. **Hosting capacity analytics will continue to evolve making it more difficult to draw clear distinctions between "methods."** While this report outlines each of the four main hosting capacity methods, in some cases it is difficult to draw clear distinction between them. As demonstrated here, hosting capacity methods have and will continue to evolve. While the industry has tried to draw a distinct line between various approaches, mainly "iterative" and "streamlined", in the future this will be irrelevant as there will likely be little means of distinction. In some cases, results seem to indicate "iterative" type approaches are beginning to adopt the mechanics of "streamlined" techniques and vice versa. Hybrid approaches, such

as that used within DRIVE, have also been developed wherein "iterative" type results are achieved using enhanced "streamlined" methods. The labels used in the industry for describing different methods will eventually be irrelevant.

5. **Methods are important, but the results are what matter most.** Hosting capacity is a complex analytical assessment. While the methods utilized to calculate hosting capacity are important and each have pros and cons that must be understood, it is recommended to focus more on the method results. Because methods are evolving, ongoing comparisons and validation are important to ensure that results continue to be meet industry expectations. As such, EPRI recommends transparency of results more so than the underlying algorithms used. Similar to smart inverter functions, rather than mandating manufacturers share complicated algorithms, the inverters are instead simply tested in order to evaluate performance. Likewise, EPRI recommends developing and publishing results from test feeders thus allowing the industry to compare and validate results consistently as methods continue to develop.

6. **Hosting capacity results are driven by the impact factors considered.** Methods matter, but so do the input data assumptions and factors considered. Not all impact factors can be considered, therefore careful consideration evaluating the appropriate impact factors is key to improving result accuracy.

7. **A hybrid hosting capacity method is the most likely path forward.** As hosting capacity methods evolve, method distinctions become even harder. As methods adopt best practices from other methods and further evolve, approaches will converge. Because of this, EPRI believes that a hybrid approach rather than one that is exclusively "streamlined", "iterative", or "stochastic" will be most successful going forward.

8. **Ongoing advancements and improvements are critical as needs become more complex.** Further innovations in hosting capacity analytics will be critical as the distribution system becomes even more complex. Grid modernization initiatives, using DER as non-wires solutions, transactive energy, all of these changes will increase the complexity of distribution analysis. Hosting capacity analytics are a key component in the assessment of distribution systems and as such the industry should continue to focus on improving the methods outlined here. Advancements to the capabilities of hosting capacity will be critical to ensuring the results of this analysis capture the needs of tomorrow.

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Docket Nos. **E002/M-17-777**
E002/M-17-776
E002/M-15-962
Xcel Energy's Miscellaneous Electric Service List

Dated this 28th day of February 2018

/s/
____
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Regulatory Administrator

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