MINNESOTA
PUBLIC UTILITIES COMMISSION

To: eDockets File

From: Commission Staff

Date: February 16, 2018

Subject: **LBNL/PSC Review of Xcel's 2017 Hosting Capacity Report**
Commission Docket (E002/M-17-777)

As indicated in the November 15, 2017 Notice of Comment Period in this docket, an award of analytic support was received by the Minnesota Public Utilities Commission from the Department of Energy (DOE) to assist in the review of Xcel's 2017 Hosting Capacity Report.

Staff has attached the report facilitated by Lawrence Berkeley National Labs and produced by Power System Consultants to this memo. Please contact staff if there are any questions related to the docket or the work product.

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Electricity Markets and Policy Group

To:	Chair Nancy Lange, Tricia DeBleeckere and Michelle Rosier Minnesota Public Utilities Commission
From:	Ranil deSilva and Randy Berry, Power Systems Consultants (PSC), for Berkeley Lab[1]
Date:	January 31, 2018
Re:	Technical review of Xcel Energy's Hosting Capacity Report (filed Nov. 1, 2017)

1. Introduction

This memo is pursuant to Task 1b of Berkeley Lab's Analytical Support for the Minnesota Public Utilities Commission (MNPUC), funded by the U.S. Department of Energy's Solar Energy Technologies Office. The memo provides a technical review of Xcel Energy's Hosting Capacity Report to the MNPUC filed on Nov. 1, 2017, in Docket No. E002/M-17-777, together with the utility's responses to initial information requests from MNPUC Staff.[2] The report updates the utility's first hosting capacity analysis submitted in 2016.[3]

Xcel's 2017 Hosting Capacity Report describes the utility's analysis of how much distributed energy resource (DER) generation — specifically, solar photovoltaic (PV) — can be interconnected to feeders on its distribution network in Minnesota. The report describes the methodology of the analysis and presents the results for about 1,000 feeders.

2. Scope of Review

MNPUC requested Berkeley Lab and PSC to:

- Review Xcel's hosting capacity report
- Comment on whether the report meets MNPUC's requirements from a technical perspective
- Compare Xcel's analysis with DER hosting analysis in other jurisdictions
- Describe current issues associated with DERs
- Discuss how hosting capacity analysis is being used elsewhere
- Make recommendations for possible improvements in Xcel's next hosting capacity analysis

[1] Lisa Schwartz, Berkeley Lab, project manager
[2] Xcel Energy, Responses to MNPUC Staff Information Requests 1-10, Jan. 10, 2018.
[3] Xcel Energy, Distribution System Study, Dec. 1, 2016.

3. Hosting Capacity Analysis by Other U.S. Utilities

The rapidly increasing penetration of DERs is affecting numerous distribution utilities around the world, many of which are evaluating DER hosting capacity on their networks. In the United States, California, New York, and Hawaii (among others) utilities are carrying out DER hosting capacity analysis similar to Xcel's analysis for Minnesota, including:

a) California
   - Pacific Gas and Electric (PG&E)
   - Southern California Edison (SCE)
   - San Diego Gas and Electric (SDG&E)

b) New York – Joint Utilities of New York
   - Central Hudson Gas and Electric
   - Consolidated Edison (Con Edison)
   - New York State Electric & Gas (NYSEG)
   - National Grid
   - Orange and Rockland Utilities
   - Rochester Gas and Electric (RG&E)

c) Hawaiian Electric Companies
   - Hawaiian Electric (HECO)
   - Maui Electric (MECO)
   - Hawai'i Electric Light (HELCO)

The California Public Utilities Commission (CPUC) provided guidance to the utilities they regulate intended to ensure a consistent approach to developing Distribution Resource Plans (DRPs), particularly with respect to considering DERs.[4] A key component of the DRPs is Integration Capacity Analysis (ICA) to identify DER hosting capacity on the distribution networks. PG&E,[5] SCE,[6] and SDG&E[7] have submitted ICA reports.

In New York, as part of the strategy for Reforming the Energy Vision, the Public Service Commission provided guidance to regulated utilities in the preparation of Distributed System Implementation Plans to incorporate DERs into their networks.[8] The guidance includes evaluation of DER hosting capacity. The Joint Utilities of New York make stakeholder presentations and hosting capacity maps publicly available.[9]

As part of the Hawaii Clean Energy Initiative, the Hawaii Public Utilities Commission provided guidance to the Hawaiian Electric Companies to develop a Grid Modernization Strategy,[10] including evaluation of DER hosting capacity. The Hawaiian Electric Companies have described their work on

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[4] Public Utilities Commission of the State of California, Assigned Commissioner's Ruling on Guidance for Public Utilities Code Section 769 – Distribution Resource Planning Rulemaking 14-08-013, filed Aug. 14, 2014.

[5] Pacific Gas and Electric Company (U 39 E) Demonstration Projects A and B Final Reports, Dec. 27, 2016.

[6] Southern California Edison Company (U 338-E) Demonstration Projects A and B Final Reports, Dec. 23, 2016.

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

[8] State of New York Public Service Commission, Order on Distributed System Implementation Plan Filings, Cases 14-M-0101 and 16-M-0411, March 9, 2017.

[9] Joint Utilities of New York, http://jointutilitiesofny.org/utility-specific-pages/hosting-capacity/.

[10] Public Utilities Commission of the State of Hawaii, Dismissing Application Without Prejudice and Providing Guidance for Developing a Grid Modernization Strategy, Docket No. 2016-0087, Order 34281, filed Jan. 4, 2017.

hosting capacity in two reports to date: *Modernizing Hawai'i's Grid for our Customers*[11] and *Power Supply Improvement Plan Update Report*.[12]

Throughout this memo, we reference work being carried out by utilities in these states.

4. Review of Xcel Energy's Hosting Capacity Report by Section

Following is a section by section review of Xcel's report. We summarize what we consider to be important points for the review and, where relevant, our own notes and opinions.

A. Background

Minnesota Statute § 216B.2425, Subd. 8 requires certain utilities to file a distribution study to identify interconnection points on its distribution system for small-scale distributed generation resources and identify necessary distribution upgrades to support continued development of distributed generation resources.[13] A MNPUC order on June 28, 2016, further required Xcel Energy to carry out an analysis of hosting capacity on each feeder by Dec. 1, 2016. In an order on Aug. 1, 2017, MNPUC provided additional clarification that the purpose of hosting capacity analysis is to inform and facilitate interconnection processes and distribution planning. The order also provided the following guidance for the utility's 2017 Hosting Capacity Report:

- Provide developers with a reliable estimate of available hosting capacity per feeder, with information in sufficient detail to inform distribution planning and upgrades needed for efficient integration of distributed generation
- Provide a color-coded map of the available hosting capacity down to the feeder level, consistent with security concerns
- Detailed information on data used in the modelling; modelling assumptions and methodologies and reasons for choosing them; and detailed information on the model used
- Estimates of the accuracy of 2016 and 2017 hosting capacity analysis

B. DER Defined

For the purpose of its hosting capacity analysis, Xcel defined DERs as sources of power on the distribution network, including generators and energy storage that are exporting power. The utility explicitly excluded load characteristics of devices, such as energy storage and electric vehicles, that are importing power. In its hosting capacity report, Xcel stated that:

"Due to the nascent nature of the energy storage market in Minnesota, we excluded energy storage load characteristics from our analysis. However, in the future we plan to monitor the ability of our hosting capacity tool with regard to energy storage, and work to extract value where it exists."

In response to MNPUC Staff Information Request No. 8, Xcel states that it has received applications for only 115 kW of battery storage systems and does not maintain a forecast for battery storage. PSC estimates that the applications for 115 kW of battery storage systems would equate to a battery consumption of only 113 MWh/year, assuming that the 115 kW of batteries are made up of 23 x 5 kW/13.5 kWh units, which are fully charged and discharged each day of the year.

[11] Hawaiian Electric Companies, Modernizing Hawai'i's Grid for our Customers, August 2017.
[12] Hawaiian Electric Companies, Power Supply Improvement Plans Update Report, April 1, 2016.
[13] Minnesota Stat. 216B.2425, Subd. 8, https://www.revisor.mn.gov/statutes/?id=216b.2425.

In contrast, Xcel has developed a forecast for electric vehicles through the year 2030 for its Minnesota service territory. Using this forecast, the utility estimates likely electric vehicle consumption of about 570,000 MWh/year by the year 2027 (in 10 years), and over 1,000,000 MWh/year by the year 2030.

PSC notes that Xcel's definition of DER is relatively narrow.[14] In PSC's opinion, Xcel's definition of DER is suited to the rapid growth in PV generation. However, it would not address the effects of possible rapid growth in domestic battery storage and electric vehicles.

C. Hosting Capacity Tool – DRIVE

For its hosting analysis, Xcel used EPRI's Distribution Resource Integration and Value Estimation (DRIVE) tool. This tool has also been used for hosting analysis by a number of other utilities including the Joint Utilities of New York.

DRIVE simplifies the elements of each feeder and then uses analytical equations to find direct solutions to the hosting capacity for each feeder segment. An alternative to DRIVE's approach is to model each feeder in detail in a classical power flow program and find the hosting capacity using iterative power flow techniques. The iterative techniques typically start with zero additional DER on the feeder and check for network violations. The DER power injection is gradually incremented and the network is monitored until a violation is reached. This determines the hosting capacity for the feeder. DRIVE's analytical approach is fast but yields approximate solutions, while iterative power flow approaches are slower but yield more accurate solutions.

Xcel has been collaborating with the Electric Power Research Institute (EPRI) in the development of the DRIVE model, and therefore has access to the tool and supporting documentation. Other parties that have not been involved in the development of DRIVE face significant costs to purchase the tool or documentation.

On page 4 of its filing, Xcel states that transparency is a key requirement for a hosting capacity study. In PSC's opinion, transparency is essential to:

a) Build stakeholder confidence in the process used for the hosting analysis.
b) Clarify the hosting methodology and allow constructive criticism from stakeholders by peer review, which can improve confidence in the accuracy of results, or highlight shortcomings that can then be corrected.
c) Help DER developers understand the technical limitations on hosting capacity and propose projects that can mitigate the limitations (for example, inverters with Volt-Var or Volt-Watt voltage support capability).

In PSC's opinion, a fully transparent analysis should enable an independent party to replicate the outputs from knowledge of the inputs and access to a freely available or low cost methodology to ensure validity of the results.

While a number of freely available EPRI documents discuss hosting capacity, it is unclear which documents apply to DRIVE.[15] An EPRI paper on the detailed DRIVE methodology costs $10,000.[16]

[14] For example, the California PUC's definition of DERs for the purpose of hosting capacity analysis includes distributed renewable generation such as PV and wind, energy efficiency, energy storage, electric vehicles, and demand response. However, the California utilities have not yet addressed all of these types of DERs in their hosting analysis. CPUC, Aug. 14, 2014.

[15] See, for example, EPRI, *Distribution Feeder Hosting Capacity: What Matters When Planning for DER*, April 2015.

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

In California, each utility has used both the iterative powerflow approach and a "streamlined" analytical approach similar to DRIVE. Both approaches are described in detail in their public hosting capacity reports.[17]

In response to MNPUC Staff Information Request No. 1, Xcel provided a summary of the DRIVE methodology. For detailed explanations of the DRIVE analysis, Xcel referred to an EPRI report, "*Distribution Planning with Distributed Energy Resources: Systemwide Assessment – Final Collaborative Report (2017).*"[18]

D. Methodology

Overview - Xcel created about 1,000 feeder models in its Synergi Electric load flow program. This program is commonly used by distribution utilities to model the distribution network and study network loading, voltages, and the effects of faults. The model data came from the utility's Geographic Information System (GIS), load forecasts and customer demand data. Xcel resolved data errors and inconsistencies and then used DRIVE to analyse the hosting capacity on each feeder.

DER Allocation Method - For the 2017 analysis, Xcel used DRIVE's "Large Centralized" method for allocating new DERs across each feeder. This method assumes that all of the new DERs will be connected at a single point on the feeder as a balanced three-phase source, and finds the highest viable DER connection for each segment along the feeder (shown on the heat map), the value of the highest viable DER connection on the feeder ("Maximum Hosting Capacity" in the spreadsheet), as well as the highest viable DER connection that can be connected anywhere on the feeder ("Minimum Hosting Capacity" in the spreadsheet). This method is intended to model the connection of PV at large commercial customer facilities.

In response to MNPUC Staff Information Request No. 2, Xcel confirms the following definitions:

- "Maximum Hosting Capacity" refers to the maximum amount of DER generation that can be interconnected on a feeder provided it is located in a suitable location. The associated "Max Limiting Factor" applies to that specific location.
- "Minimum Hosting Capacity" refers to the maximum amount of DER generation that can be interconnected anywhere on a feeder, irrespective of location. The associated "Min Limiting Factor" applies to a specific point on the feeder where generation location becomes a concern.

In its 2016 hosting capacity analysis, Xcel used the "Small Distributed" method for DER allocation. The Small Distributed method assumes all new DERs are spread along the feeder with a normal distribution, with the central peak at a specific location. This method is intended to approximate the connection of large numbers of small PV installations spread across multiple households and evenly divided between the three phases. In reality, individual small inverters are typically connected to the low voltage secondary system on either one, two, or three phases. In response to MNPUC Staff Information Request No. 7, Xcel explains that it does not have the detailed information on the secondary low voltage conductors required to model the secondary low voltage networks. PSC notes that this is common among utilities.

Xcel states that it is responding to stakeholder feedback in changing to the Large Centralized method in its 2017 analysis. Xcel's forecasts suggest that new DER connections will be mostly large commercial installations instead of small domestic connections. PSC believes that this approach may

[17] PG&E, Dec. 27, 2016; SDG&E, Dec. 22, 2016; SCE, Dec. 23, 2016.
[18] PSC has not been able to locate this report online.

overlook any rapid (and often viral) uptake in domestic rooftop PV that is prevalent in other jurisdictions. Some developers in other jurisdictions are installing PV on multiple household rooftops, owned by the developer and rented by the homeowner. In Minnesota, projects are being facilitated by a third party, but owned by a community or homeowner. In terms of total capacity (megawatts), small and distributed domestic PV has the potential to be larger than the large centralized commercial PV. PSC suggests that in future hosting capacity analysis, Xcel include results using both the Small Distributed method and the Large Centralized method.

E. Assumptions

Data - Xcel assumed that its source data from GIS is correct. Unusual data was corrected before being used by DRIVE.

The assumption of GIS data accuracy, together with some data validation, is typical for hosting capacity analysis carried out by other utilities such as PG&E,[19] SCE,[20] and SDG&E.[21] In PSC's opinion, this is an appropriate and pragmatic approach for a wide area study, especially considering that specific applications for DER interconnection will be subjected to a more thorough analysis.

Secondary Conductors Not Modelled - Xcel's hosting analysis considers primary medium voltage feeders and excludes secondary low voltage conductors supplying the customer. This is due to the lack of available information about the secondary conductors. However, the analysis assumes a 3 volt drop in the secondary conductors when calculating voltages.

In PSC's opinion, excluding low voltage conductors is a pragmatic decision as this information is typically not recorded for many customers. Also, Xcel's focus on Large Centralized DERs means low voltage conductors can be neglected because large DERs will directly connect to the primary voltage feeders.

Conductor Spacing – Conductor spacing affects the impedance of the feeders. Xcel assumed a standard conductor spacing for the majority of the feeders which operate at 13.8 kV.

In PSC's opinion, this assumption is adequate for screening purposes, as non-standard conductor spacing can be considered in the detailed interconnection studies.

Capacitors – Xcel assumed that capacitor banks were switched on at peak demand, but were switched off in case of over-voltage. For off-peak demand, capacitors were switched off by DRIVE to mimic actual operation.

In PSC's experience, distribution capacitor banks are typically switched on at peak demand, so this is an appropriate assumption.

Loading Levels – Xcel typically used SCADA data to determine the peak feeder load and daytime minimum load (because only daytime is relevant to PV hosting). If SCADA data was not available, Xcel determined peak loads from substation monthly data, and assumed daytime minimum load is 20% of the peak load. This assumption has been validated by observing the actual minimum loads on Xcel feeders that do have SCADA.

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[19] PG&E, Dec. 27, 2016, Section 4.c.
[20] SCE, Dec. 23, 2016, Section 4.3.2.
[21] SDG&E, Dec. 22, 2016, Section 4.c.i.

Load Allocation – Individual loads on each feeder were allocated based on load curves for customer type and energy usage, or using primary metered data for some customers. This method of load allocation is also used in California, New York, and Hawaii.

Feeder Topology – Xcel used the feeder switching status from a snapshot of a single point in time. This implies that most of the network was in its normal configuration, but a few parts of the network would likely have been switched into a maintenance configuration. Xcel notes that feeder topology is regularly reconfigured during operations, implying that the hosting capacity results will change for different topologies.

PSC suggests that Xcel consider modelling the normal operating feeder topology for the hosting capacity analysis. Different topologies that may occur during maintenance may be better studied during detailed investigations. Note that the California utilities only analyse the normal topology, which is consistent with the process for interconnection studies.

Head End Voltage – Xcel assumed that the substation end of the feeder (the "head end") is set to 104% of nominal voltage. The utility made this selection to represent a worst case scenario for over-voltages.

PSC notes that if battery storage or electric vehicle charging were to be considered in the analysis, *under*-voltage would become an important criteria and a lower head end voltage would need to be assumed.

Distributed Generation Output – Xcel assumed that DER was operating at 100% output for the hosting analysis. This is consistent with the approach of utilities in California, New York, and Hawaii.

F. Thresholds

Xcel used six thresholds to determine the hosting capacity of each feeder (out of 11 available in DRIVE):

1) Primary over-voltage - 105% (under-voltage is not considered as Xcel ignores energy storage)
2) Primary voltage deviation - 5% (allowed change in voltage as all PV output on the feeder rapidly changes from full to zero). In response to MNPUC Staff Information Request No. 6, Xcel explains that while it had originally intended to allow a 3% deviation for an individual PV output rapidly changing from full to zero, the DRIVE tool's default 5% aggregate threshold was equivalent to 5% for all DERs on the feeder changing from full-on to full-off.
3) Regulator voltage deviation - 50% (allowed change in voltage as a fraction of the voltage regulator tap control bandwidth)
4) Thermal for discharging DERs - 100% (thermal for charging DERs is not considered as Xcel ignores energy storage)
5) Additional fault current - 10%
6) Breaker relay reduction of reach - 10% (reduction in fault current)

PSC considers these thresholds appropriate for DER as an energy source, with the possible exception of item (2) Primary voltage deviation - 5%. Cloud cover is likely to reduce PV output on multiple feeders simultaneously — not just one feeder — which could result in a voltage deviation exceeding the 5% threshold. This effect is not modelled by Xcel. Thus, we believe that Xcel's hosting capacity results may be optimistic with respect to voltage deviation.

G. Impacts and Mitigation

Xcel describes the general types of mitigation that could be applied to increase hosting capacity. The utility notes that a detailed study will be required to determine the most cost-effective mitigation for individual feeders.

Low cost mitigations cited in the report include:

a) Adjust DER power factor settings
b) Adjust voltage regulator settings
c) Adjust relay settings

Higher cost mitigations cited in the report include:

a) Replacing protection relays
b) Reconductoring feeders

PSC notes that additional mitigation options are available, such as:

a) Local battery storage to absorb PV output when necessary
b) Volt/Var and Volt/Watt controls on advanced PV inverters to regulate voltage
c) Distribution STATCOMs to regulate feeder voltage[22]

H. Accuracy

MNPUC required Xcel to estimate the accuracy of the previous (2016) hosting capacity results as well as the latest 2017 results. The utility performed this analysis by comparison with detailed interconnection studies.

Xcel notes that this comparison is difficult because of differences in modelling software, omission of existing distributed generation (2016), changes to thresholds for voltage deviation and breaker reach, differing assumptions about mitigations, and different assumptions about head end voltage.

Xcel estimated the accuracy of the 2016 hosting capacity results by comparing the hosting results for six feeders with screening studies associated with recent interconnection applications. The 2016 hosting results were generally slightly conservative compared to the screening results.

Xcel estimated the accuracy of the 2017 hosting capacity results by comparing the hosting results for five feeders with studies associated with recent interconnection applications. In all five cases, the hosting capacity results were consistent with the interconnection study results (after study discrepancies were corrected).

I. Results

Xcel presented the results of the 2017 hosting study in tabular form and as a visual heat map. The tables state both the minimum and maximum hosting capacities, along with the respective limiting factors. The heat map shows the hosting capacity for each segment along each feeder, providing useful information about the preferred locations for DERs along a feeder.

[22] A STATCOM is a type of inverter with no energy source that is used to control voltage. It can inject or absorb reactive power but not active power.

J. Non-Public Data

To protect customer privacy and confidentiality, or protect critical distribution infrastructure information, Xcel does not display some feeders on the heat map. However, hosting results for these feeders are still presented in the tables.

In addition, the feeders that are displayed are shown with a buffer zone to hide exact route details for feeders. PSC notes that the equivalent heat maps for California and New York show the feeder routes without a buffer zone. The equivalent heat maps for Hawaii do include a relatively wide buffer zone.

5. Compliance with MNPUC Technical Requirements

We discuss here what we consider to be MNPUC's key technical requirements for the hosting capacity analysis and provide our assessment of how Xcel met those requirements.

Level of detail – *Provide sufficient detail for the hosting capacity per feeder to provide developers with a starting point for interconnection applications.*

Xcel provides details of the DER generation hosting capacity per feeder, including the minimum and maximum hosting capacity, and the associated limiting factors.

PSC notes that MNPUC did not require for the 2017 Hosting Capacity Report further details of hosting capacity, including for:

a) Different sections that make up a feeder
b) Each hour of the year
c) DER beyond solar PV, such as battery storage and electric vehicles

PSC notes that California utilities provide these three additional levels of detail in their hosting capacity analyses.

Map of hosting capacity – *Provide a color-coded map of hosting capacity down to the feeder level, consistent with security concerns.*

Xcel provides a color-coded heat map of hosting capacity, showing the hosting capacity for each segment along the approximate route of each feeder. To maintain security, the routes are approximated by a buffer zone, and some feeder routes are not shown at all.

PSC notes that equivalent maps by California and New York utilities show the exact route for each feeder, while Hawaii shows a much broader buffer zone than Xcel.

Spreadsheets – *Provide downloadable spreadsheets of the hosting capacity results.*

Xcel provides downloadable spreadsheets of the hosting capacity per feeder, including the minimum and maximum hosting capacity, and the associated limiting factors.

Modelling assumptions and methodology – *Provide modelling assumptions and methodology.*

In response to MNPUC Staff Information Request No. 1, Xcel provided a summary of the DRIVE methodology. For detailed explanations of the DRIVE analysis, Xcel refers to an EPRI report, *"Distribution Planning with Distributed Energy Resources: Systemwide Assessment – Final Collaborative Report (2017)."*

Accuracy – *Provide estimates of the accuracy of the results by comparison with interconnection studies.*

As discussed in Section 4H of this memo, Xcel estimated the accuracy of the 2016 and 2017 hosting capacity results by comparison with studies associated with recent interconnection applications.

In PSC's opinion, this is a valid method of estimating accuracy, even though the number of comparisons was limited to six feeders in 2016 and five feeders in 2017 due to difficulties in making comparisons on a like for like basis.

6. Current Issues Associated with Hosting DER

In this section, we discuss current issues with hosting DERs at a global level, and how these issues might affect Xcel's hosting analysis in Minnesota going forward.

Rapid evolution in DER technology and standards – DER technology is still in its infancy compared with traditional technologies such as synchronous generators. The technology is rapidly evolving, especially with respect to inverter controls. International technical standards tend to require several years to develop due to the level of consensus required. However, inverter manufacturers are developing and offering control systems in advance of standards being accepted.

Xcel's definition of DERs for its hosting analysis is presently restricted to energy sources, and does not include storage and electric vehicles. Further, Xcel states that it is awaiting a revision to the IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems before applying a new definition of DER (the revised standard includes storage).

Tools for analysing hosting capacity are also rapidly evolving, with the EPRI DRIVE tool used by Xcel offering new features that are yet to be incorporated into Xcel's hosting analysis:

a) Calculation of network losses – This feature could be used to demonstrate how DERs could reduce network losses and the associated overall generation requirements.
b) Analysis of non-three phase systems – This feature could allow low-voltage secondary networks to be analysed, which are typically not three phase. (This would require additional data on the secondary conductors, which Xcel does not have at present.)

Growth in domestic rooftop PV, battery storage, and electric vehicles – Many jurisdictions are experiencing a rapid uptake in domestic rooftop PV, as well as a more modest uptake in domestic battery storage and electric vehicles. Some of the PV installations have been subsidised by government or ratepayer-funded incentives for renewable energy, but these subsidies are diminishing as domestic PV is becoming economically viable in its own right.[23]

Penetration levels of customer-hosted solar PV are expected to continue to increase. For example, Hawaii is currently challenged by extremely high levels of PV penetration, while California has high levels of PV penetration, and New York is preparing for increased PV penetration.

There is a growing concern that charging battery storage and electric vehicles could potentially overload the distribution network. Potential mitigations include controlling DERs to restrict charging

[23] For example, see https://energy.gov/revolution-now.

to times of light demand. On the other hand, battery discharge can also reduce loading on the distribution network when used to supply local load at times of peak demand.

Xcel's hosting analysis exclusively addresses PV, but does not yet consider battery storage or electric vehicles. If storage and electric vehicles are included in the hosting capacity analysis, Xcel will need to include additional network thresholds that are available in DRIVE but not yet used by Xcel (including undervoltage and thermal limits for charging DERs).

Advanced inverter functions – Inverter controls are becoming available so that DERs can provide support to the electricity network. These controls could potentially increase hosting capacity without requiring other mitigations. These advanced functions include the following:

a) *Power factor controls can be set to help voltage control on feeders* (required in the draft IEEE 1547 standard). Xcel requires inverters of PV connected to its distribution system to be able to operate with a fixed power factor in the range of +/- 0.9, and its hosting capacity analysis assumes a power factor of 0.98 (absorbing Vars) for new inverters.
b) *Volt-Watt and Volt-VAr controls can help regulate feeder voltage* (required in the draft IEEE 1547 standard). For feeders with highly resistive impedances, Volt-Watt control can regulate voltage by adjusting active power output. For feeders with highly inductive impedances, Volt-VAr control can regulate voltage by adjusting reactive power output. Volt-Watt and Volt-VAr controls are not currently available in DRIVE and consequently not represented in the analysis.
c) *Fault ride-through controls allow inverters to continue operating after major voltage or frequency disturbances* (required in the draft IEEE 1547 standard). This helps to avoid loss of generation just after a fault is cleared. Fault ride-through controls are not modelled in Xcel's analysis, which focuses on steady state conditions.
d) *Power ramping controls limit the rate of increase of power output from PV inverters as cloud cover reduces.* This reduces the impact of sudden increases in PV generation on feeder voltage. Power ramping controls are not modelled in Xcel's analysis. PSC notes that even if they were modelled, the sudden decrease in power as cloud cover increases would still be a problem.
e) *Soft start controls stagger the timing of reconnecting inverters if they are tripped during a major disturbance.* This gives the network time to adjust to the power injected by the reconnecting inverters. Soft start controls were not modelled in Xcel's analysis.

System-level hosting capacity – Most distribution utilities have focused their hosting capacity analyses on the feeder level but recognize that this needs to be expanded to the overall system level. The next logical step is to calculate the hosting capacity for an entire distribution substation, including the main substation transformers, all connected feeders, and the local transmission network. As DER penetration increases, utilities do more detailed studies on the system impacts for their service territories.[24]

Some utilities are facing such high penetrations of inverters at the system level that they now need to dispatch synchronous generators to maintain sufficient system strength to avoid system collapse. For example, in Ireland, the system operator restricts inverter-connected generation to 55%.[25] In South Australia, the penetration of inverter-connected wind generation has reached as high as 120% (with power being exported to other states), and the system operator has developed system

[24] However, it's important to note that high localized DER penetration can be a problem even if systemwide DER penetration is low.
[25] DS3 program update: https://www.gaelectric.ie/ds3-a-summary-update/.

strength criteria stipulating the number of synchronous generators that must be online for different levels of inverter generation (particularly wind generation).[26]

Locational benefits of DER – In addition to hosting capacity analysis, some regulators such as the California PUC require utilities to carry out a Locational Benefits Analysis aimed at finding the economic benefit of installing DERs at specific points on the distribution network. This analysis is typically intended to find out if it is more cost-effective to install DERs rather than upgrading the distribution network.

Effect of network switching on hosting capacity – Distribution utilities carry out switching operations on the network, typically to allow maintenance on parts of the network. Network switching changes the topology of the network, and consequently changes the hosting capacity.[27] Note that the California utilities only analyse the normal topology, which is consistent with the process for interconnection studies.

7. Usage of Hosting Capacity Results

Regulators in other states (California, New York, Hawaii) that have required distribution utilities to carry out hosting capacity calculations all have similar goals for the results. In general, the regulators want to use the hosting capacity results so that utilities, DER developers, and customers are better informed about locations where DERs can be installed without mitigations to the distribution system, and use DERs to avoid or defer the cost of certain types of traditional network upgrades. Xcel has similar goals. However, the utility's hosting capacity report does not discuss the use of DERs to avoid or defer network upgrades.

The California PUC views the hosting capacity results from the regulated utilities' Integration Capacity Analysis, along with a Locational Value Analysis and future DER growth analysis, as a "… *set of mutually supportive tools that detail how much DER can be deployed under a business as usual grid investment trajectory, and build the capabilities to compare portfolios of DERs as alternatives to traditional grid infrastructure."*[28] Specifically, the Locational Net Benefits Analysis in California will be used to help identify how to avoid utility costs in increasing distribution capacity, increasing transmission capacity, maintaining power quality, and maintaining reliability. The avoided costs are displayed as a heat map showing utility investment deferral value in $/kW of DER.[29] Other states are beginning to analyse locational value of DERs as non-wires alternatives for certain types of distribution system upgrades.[30]

The New York Public Service Commission anticipates that "*Hosting capacity data can be used to support DER developers' understanding of more favorable locations for interconnection of*

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[26] "South Australia System Strength Assessment," Australian Energy Market Operator, September 2017.
[27] Some utilities use automated network switching applications (Fault Location, Isolation, and Supply Restoration – FLISR) to improve reliability. A change in hosting capacity can be expected regardless of whether manual or automated switching is carried out.
[28] CPUC, Aug. 14, 2014.
[29] "Pathways to an Open Grid: Locational Net Benefit Analysis Best Practices - Deep Dive on California's Locational Net Benefit Analysis (LNBA) Public Tool," PG&E, Jan. 17, 2018. Available at http://pathways-opengrid.com.
[30] For example, see State of New York Public Service Commission, "In the Matter of the Value of Distributed Energy Resources." *Order on Net Energy Metering Transition, Phase One of Value of Distributed Energy Resources, and Related Matters,* March 9, 2017. http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7b5B69628E-2928-44A9-B83E-65CEA7326428%7d; State of New York Public Service Commission. *CASE 14-M-0101 – Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision. CASE 16-M-0411 – In the Matter of Distributed System Implementation Plans: Order on Distributed System Implementation Plan Filings*. http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={F67F8860-0BD8-4D0F-80E7-A8F10563BBA2}.

Distributed Generation (DG), enable distribution planners to consider DER in system planning, and inform utility interconnection processes."[31]

The Hawaiian Electric Companies[32] view their hosting capacity analysis as part of a staged evolutionary planning process:

> *"Walk Stage - Hosting capacity used for indicative information for DER developers. DERs are evaluated individually and collectively through iteration.*
> *Jog Stage - Hosting capacity analysis is used in the planning process to assess potential upgrades to enable forecast of DER growth. DERs are considered as a portfolio but not optimized.*
> *Run Stage - Hosting capacity analysis is used within the interconnection process. Simultaneous assessment of DER portfolios to further optimize hosting capacity."*

8. Summary of Recommendations for Improvements

Xcel intends to progressively refine and improve its DER hosting analysis each year. PSC makes the following recommendations for improving hosting capacity analysis in the next analysis cycle:

1) Analyse and present hosting capacity for a range of periods during the year, not just for the peak and minimum demand. Timing information will help developers understand when DERs are most useful or should be curtailed. (The CPUC requires California utilities to calculate hosting capacity for each hour of the year.)
2) Add total quantities of existing DERs and queued DERs to the published tables of hosting capacity for each feeder. This will help developers better understand the technical environment they are working in.
3) Widen the types of DERs considered in the hosting analysis, such as battery storage and electric vehicles (if forecasts predict a high uptake).
4) Expand the analysis to include both the Small Distributed method as well as the Large Centralized method for DER allocation to show the hosting capacity available for future high uptake in domestic rooftop PV.
5) Modify the methodology used to estimate the primary voltage deviation threshold (presently limited to 5%) to account for cloud cover that may reduce PV output on multiple feeders simultaneously (not just one feeder as presently modelled). In PSC's opinion, Xcel's hosting results may be optimistic with respect to voltage deviation due to their analysis ignoring cloud effects on adjacent feeders.
6) Model the normal operating feeder topology for the hosting analysis (not just the topology at the time the network snapshot was taken). Different topologies that may occur during maintenance may be better studied during detailed investigations.
7) Incorporate more advanced inverter functions into the analysis, as they become available in the DRIVE tool.
8) Gradually extend the hosting analysis from a feeder level to a system level to help understand how much DERs can be hosted at a substation, or Minnesota-service territory-wide.

[31] NYPSC, March 9, 2017.
[32] HPUC, Jan. 4, 2017.