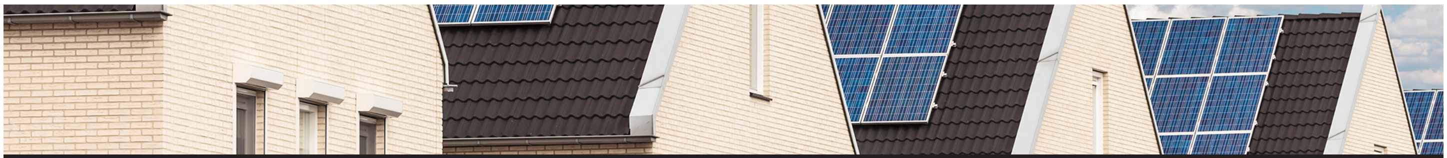
Distribution Feeder Hosting Capacity: What Matters When Planning for DER?

April 2015



Overview

The potential impact high penetration distributed energy resources (DER) has on distribution system performance, and ultimately the amount of DER a feeder can accommodate, depends upon many factors including such items as the distribution feeder and DER characteristics, location of the DER along the feeder, feeder operating criteria and control mechanisms, and electrical proximity of DER to other DER systems.

Some distribution feeders can accommodate considerably higher levels of DER before operating criteria are violated, while others will be able to accommodate lower levels of DER. The level of accommodation can also change in time on changes to a feeder or the addition of new DER systems.

What is Hosting Capacity?

Hosting capacity is defined as the amount of PV that can be accommodated without impacting power quality or reliability under existing control and infrastructure configurations

This paper provides an overview of the hosting capacity method developed to determine the ability of feeders to accommodate DER. The impact from DER is recognized as dependent on the feeder and DER characteristics, both of which are continually changing due to normal feeder growth and both planned and unplanned reconfiguration. While the focus of this paper is on PV, many of the items addressed are applicable to other forms of DER as well (storage, wind, CHP, etc).

The Need for a Method

In 2010, EPRI initiated a Distributed PV Feeder Analysis project to determine the impacts of residential/commercial (small-scale) and utility class (large-scale) distributed photovoltaic generation on the distribution system. This project gained momentum as utility concerns began to develop from increasing penetration levels of PV as well as concerns over potential impacts when fast-tracking large numbers of small PV interconnections that are not studied.

Traditional system planning techniques are well established in the power systems industry yet the majority of distributed PV systems are installed without such thorough analyses. The time and effort to conduct these studies can be impractical to many utilities due to limited personnel, while to others, the perceived impact of small PV systems may be negligible. This can be the case for the first few installed systems, however many utilities are faced with the question—at what point will I begin to see issues?

That point which issues may begin to arise is the feeder hosting capacity. Hosting capacity is defined as the amount of PV that can be accommodated without impacting power quality or reliability under existing control and infrastructure configurations. Every feeder has a hosting capacity for distributed PV. This hosting capacity can change as the feeder changes configuration and design changes. When the total PV on the feeder is near or above this limit, adverse impacts are likely to occur. Determining a feeder's hosting capacity for DER is not a straightforward process nor is it a single value for any given feeder. However, EPRI has developed and implemented a method that determines a feeders hosting capacity and has applied the method throughout many distribution systems in the US.

Hosting Capacity Method

Every distribution feeder is rather unique due to the endless combinations of voltage class, conductor type, topology, and other feeder characteristics. The feeder design itself provides part of the uniqueness, but the customer dynamics also play a role. As a result of this diversity, all feeders will have a unique response to

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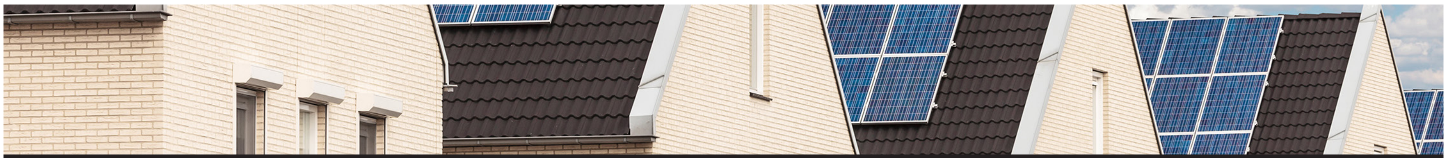


distributed photovoltaics and therefore a unique amount of PV that can be accommodated before facing an impact. This feeder hosting capacity will be dependent on the feeder, PV deployments, and specific utility-established thresholds

The hosting capacity method is rooted in two key areas that are critical for ensuring effective DER integration:

- **voltage** – the voltage analysis considers over and under voltages (primary and secondary), voltage regulation, changes to equipment operation (regulators & load tap changers (LTCs), switched capacitor banks), and
- **protection** – the protection analysis considers protection coordination issues due to changes in fault current including: relay desensitization, sympathetic tripping, and increased fault duty.

Other Aspects to Consider

Hosting capacity isn't the only aspect to consider, including thermal capacity and energy impacts. DER can also provide services that benefit the grid, including voltage support as well as loss and peak demand reduction. Losses can be reduced because local generation replaces power otherwise produced far from load. Reducing peak demand allows deferral of asset upgrades at the distribution level, and may also lessen the need for generation capacity at the system level. Variable generation that is not dispatchable may not be able to provide capacity to the grid and therefore the characteristics of the DER itself are critical to when the resource can provide this type of service.

Applying the Method

When applied, the hosting capacity method provides a range of possible higher penetration scenarios that determine both a more and a less conservative hosting capacity (minimum and maximum hosting capacity). Figure 1 provides an example of this application when considering maximum primary feeder voltage as a function of total PV on the feeder. Each marker indicates the absolute maximum primary feeder voltage for a unique PV deployment. There are also three regions (A,B,C) identified in the figure.

Region A includes PV deployments, regardless of individual PV size or location, with primary voltages below the ANSI 105% voltage threshold (threshold shown by horizontal line). At the start of Region B, the first PV deployment exceeds the voltage threshold. This PV penetration level is termed the Minimum Hosting Capacity because the total PV in the deployment is the lowest that causes adverse impact. The rightmost side of Region B defines the Maximum Hosting Capacity where all PV deployments, regardless of individual PV size or location, begin to cause primary voltages in excess of the threshold. Region C continues with all deployments exceeding the threshold regardless of individual PV size or location.

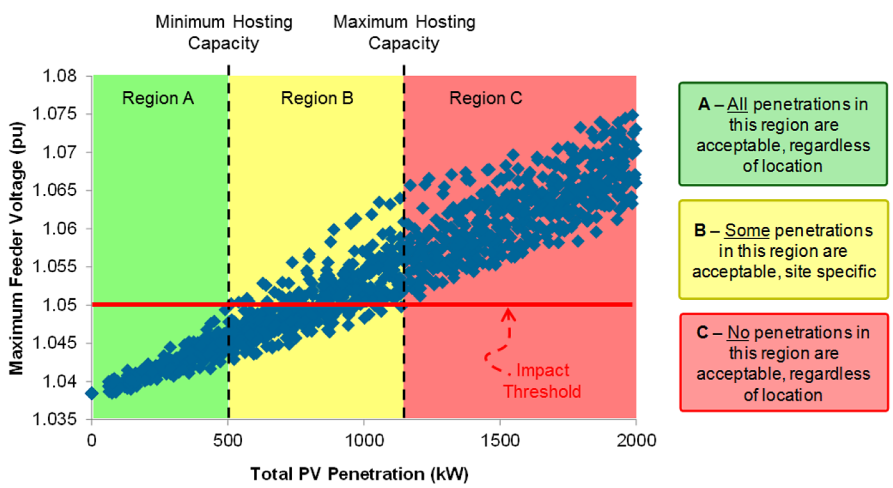
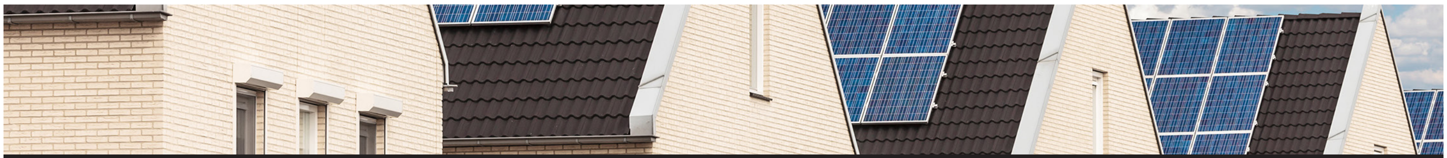


Figure 1 – Feeder Hosting Capacity: Maximum Primary Voltage as a Function of Total Penetration Voltage



A brief summary of the various criteria that can impact hosting capacity is briefly summarized here:

Overvoltage: The hosting capacity on a particular feeder will be dependent on the thresholds used for the calculation. Operating conditions such as conservation voltage reduction (CVR) could reduce the hosting capacity. These feeders may have additional headroom before reaching the ANSI voltage limits, but the operating strategy may dictate the voltages be kept at lower levels.

Voltage Deviations: In addition to overvoltage, the hosting capacity can also be limited by how much the DER changes the voltage. Voltage changes (deviations) may not have a strict ANSI threshold; however, they could cause voltages to suddenly swing above/below operating limits. In addition, this can cause additional control (regulator/capacitor) operations or tripping of sensitive equipment.

Protection: As mentioned previously, system protection is another critical aspect that can determine hosting capacity. Distributed generation has the potential to disrupt protection schemes and requires evaluation. The fault contribution from inverter based generation can be short in duration due to fast acting controls; however, the magnitude will be based on the inverter control and not the impedance to the fault. In other words, the fault contribution will be in the range of 1-2 times the full load current and potentially higher. Studies with these contributions allow calculation of hosting capacities for issues such as sympathetic breaker tripping, breaker reduction of reach, and fuse coordination with other protection devices. As with all distributed generation, the impact will be more significant as the zero sequence (ground) fault contribution increases.

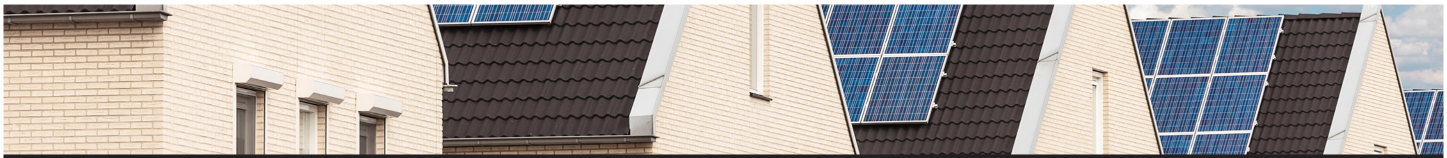
Unbalance during Faults: The fast acting (tripping) of inverters can limit the fault contribution; however, can also lead to additional issues especially in the presence of higher ground fault currents. In the case of a single-phase fault, all inverters of that particular phase can trip, causing the ground currents to jump at the substation. This change in ground current can inadvertently cause the substation ground fault relay to trip the feeder.

Unintentional Islanding: Anti-islanding remains a concern as well even with the presence of inverter destabilization controls that are constantly searching for the islanded condition. An issue with these destabilization controls is that conflicting objectives between various brands of inverters can potentially delay or miss the detection of an island before automatic feeder control devices try to reclose on the island. Using a direct transfer trip or making sure the total PV does not exceed the local load are the most definite ways to prevent an unintentional island but would either add significant cost or severely limit the amount of PV on the feeder.

While still considered in the hosting capacity method, issues not as severely impacted by PV contribution include voltage imbalance, thermal overloading, and harmonics. Voltage imbalance impacts can be minimal under the assumption of heavily loaded phases becoming more compensated with single-phase PV, thus reducing voltage unbalance. There remains the case that clustering of PV can occur at particular locations such as in zero net energy neighborhoods that would increase unbalance. Under a similar assumption, the heavily loaded phases will also be less thermally stressed with the addition of PV. The caveat is that the installed PV systems must not severely outweigh the customer size; otherwise, the potential for reverse power flow could overload system elements. Harmonics are also a low issue because inverters are commonly ungrounded beyond their isolation transformer. This design limits the harmonics ever making it back to the source. The other condition is that the power injection from PV will commonly increase the fundamental voltage and thus decrease the harmonics calculated as a percent of the fundamental.

Tale of Two Feeders

As has been discussed, the hosting capacity can be unique for all distribution feeders. From a detailed analysis of two feeders whose characteristics are similar, with the exception of line length and number of feeder regulators, the hosting capacity of each feeder is quite different. The hosting capacity is not correlated to feeder loading. As shown in Figure 2 on page 3, one feeder can accommodate any PV deployment to 2.2 MW (approximately 30% of peak load), while the other feeder should be limited to 0.5 MW (approximately 16% of peak load). Higher penetrations could occur on both feeders but would be dependent on PV location. This example is used to illustrate the feeder hosting capacity is not solely dependent on feeder loading. The hosting capacity for distributed PV is determined from a complex analysis that must take into consideration all characteristics used to describe the particular feeder.



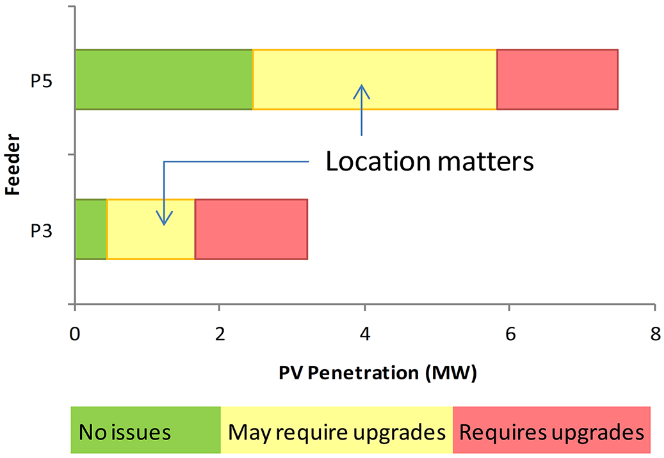


Figure 2 – Hosting Capacity Results for Feeders with Similar Characteristics

Every Feeder is Different–What Matters?

In analyzing 34 Feeders across the U.S., one thing is clear—the amount of distributed energy resource (DER) that can be accommodated without upgrading the system varies between distribution systems and within feeders in a system. The main factors that drive the amount of PV that can be hosted, without necessitating changes in how the grid is constructed or operated, are: 1) DER size and location, 2) distribution system physical characteristics, and 3) DER technology. All of these factors are critically important in evaluating the impact of PV to the grid.

Size and Location

Centralized, utility-class (wholesale) DER generation results in specific impacts to the grid based upon where it is located along a distribution feeder. Meanwhile, customer-based generation dispersed throughout a feeder likely has a vastly different impact for the same amount of energy produced by centralized utility-scale plants sited in one or more locations. Due to the wide range of PV sizes and locations, the hosting capacity of any given feeder is not a single value, but a range of values depending upon the location of the resources.

Distribution Feeder Characteristics

Distribution feeder characteristics also determine how much PV can be hosted. Voltage class, feeder topology, and load location are just some of the factors that determine what level of PV can be accommodated and where. Even though feeders may appear to be similar when compared using conventional characterizations, EPRI analyses of feeders throughout the U.S. have consistently shown that easily observed feeder characteristics alone cannot definitively and accurately determine hosting capacity.

Location Matters

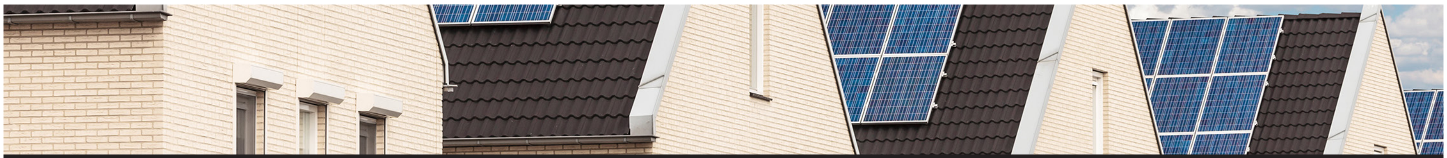
Due to the wide range of PV sizes and locations, the hosting capacity of any given feeder is not a single value, but a range of values depending upon the location of the resources.

DER Technology

Variable generation such as wind and solar can have widely varying impacts on voltage and capacity value compared to other forms of generation that are dispatchable. The differences primarily emanate from the timing in which the energy is generated and the character of the energy output. The specific DER technology employed is also a factor. Rotating machines and

Table 1 – Critical Factors that Determine Distribution Hosting Capacity for DER

DER Size and Location	Feeder Characteristics	DER Technology
Highly Distributed, Residential-based	Voltage Class	Variable Generation (Solar, Wind)
Centralized, Commercial-based	Load Level/Location	Non-variable Generation (CHP, Fuel Cells, Etc)
Centralized Wholesale	Conductor Type/Miles	Inverter vs Machine-based
	Voltage Control Scheme	
	Protection Scheme	



static inverter interfaces have different impacts on system protection, for example.

These core factors—and others, such as the operation of other systems like conservation voltage reduction, whether the feeder is radial or networked, etc.—can result in a wide range of feeder hosting-capacity thresholds. These interactive effects are important because in some cases, accommodating DER produces a positive collateral effect, while in others it does not. These distinctions must be recognized at the feeder level so that impacts are fully accounted for.

Filling an Industry Gap

Traditionally, distribution planners had fewer interconnection requests and were able to analyze each DER as they came in. More recently as applications have increased, utilities have begun employing fast-track methods like the "15% rule" for peak feeder load. These are intended to be conservative methods, but have taken the dependence on actual feeder characteristics out of the equation. Cognizant of the importance of factors that vary widely among feeders, some utilities are now looking to cluster feeders based upon topology, and model a single (representative) feeder from each feeder "type." Each of these "less than detailed" methods seeks to overcome the intensive labor needs, complexity issues, and extensive data inputs required to perform a rigorous analysis on each individual feeder. However as has been shown, only information about the specific feeder under review can provide accurate and actionable information about hosting capacity.

EPRI analysis has shown that feeders clustered together based on general physical characteristics may not accurately reflect how much PV a feeder can host. As shown in Figure 2, two feeders that were clustered together based upon shared, high level characteristics were found to have considerably different hosting capacities for solar PV.

EPRI has determined that using a percentage of feeder loading as a means of estimating feeder hosting capacity can result in over- or under-estimation of feeder hosting capacity for PV. The hosting capacity method described earlier overcomes some of these challenges, however it does require a rather rigorous and time consuming analysis. More efficient methods that streamline the study process would help overcome these limitations.

Streamlined Hosting Capacity Method for Planning

The industry needs a better method for accurately determining feeder hosting capacity that distinguishes among the dimensions of DER size/location, feeder characteristics, and DER technology on the performance of individual feeders and the distribution system. To garner widespread acceptance by electric utilities and grid operators, a developed method must be comprehensive enough to apply efficiently to an entire utility's (or region's) thousands of distribution feeders, but capable of also distinguishing the important factors that affect hosting capacity. In addition, to be feasible it must integrate into existing distribution planning software without requiring distribution planners to learn and adapt to a different set of tools.

To fill this need, EPRI has developed a Streamlined Hosting Capacity Method[1] that provides the industry with a tool to perform this analysis on a system-wide basis more quickly without compromising accuracy. This analysis does not replace the detailed analysis, but provides a step in between simplified screens and

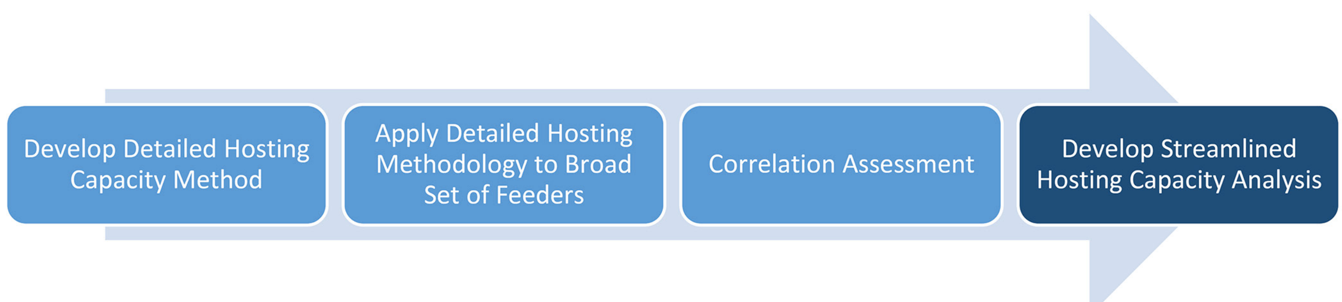
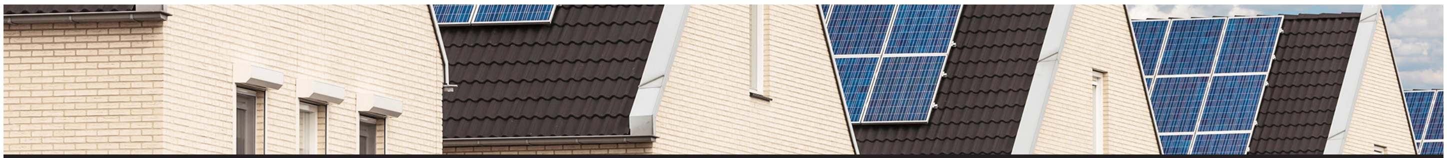


Figure 3 – Evolution of the Streamlined Hosting Capacity Analysis

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



detailed analysis that allows utilities to perform a quicker analysis and determine if a detailed study is needed.

The streamlined hosting capacity method and analysis has been developed through multiple years of research on distributed PV impact studies. The evolution of the methodology is shown in Figure 3. The detailed hosting capacity analysis examined millions of potential PV deployments across more than 30 feeders while examining the impact to the full range of potential issues discussed previously. Utilizing the detailed approach, the engineering time associated with a single feeder was on the order of weeks. However in the streamlined method, a single feeder can be analyzed in a matter of minutes through the newer methods and automated nature of the analysis. The simulations and impacts observed on specific feeders have been beneficial in determining how DER can impact the distribution system as well as providing the utility a screening criteria for the particular feeder.

The value of such a method is significantly greater when accessible within the distribution system analysis tool used by the utility distribution engineer. The streamlined methodology has been developed in such a manner which would allow it to be readily used in commercially-available distribution planning tools (CYME, Synergi, Milsoft, etc). This will enable the utility to conduct analyses when and as often as necessary without having to learn a new software program or waste countless hours working with large amounts of data to run select cases.

The focus of this method is to quantify, on a feeder-by-feeder basis, individual hosting capacities, and locational impacts. The broader application of this methodology is to expand the scope of analyses to entire systems. While some details are not captured, the beneficial applications outweigh the potential loss by allowing system-wide assessments to be performed. Table 2 describes key applications for the streamlined method.

Table 2 – Potential Applications of the Streamlined Analysis

Potential Applications of the Streamlined Method	
How much DER can a feeder host?	Determine the existing hosting capacity for each feeder across the entire distribution system under current grid configurations
Where is the “optimal” location for DER?	Identify locations that can minimize the upgrades necessary to accommodate DER
Can PV interconnect w/o causing adverse issues?	Improve screening techniques that efficiently account for the proposed DER and associated grid capacity at that location
What is the aggregate level of DER that can be accommodated at the substation level?	Improve visibility into substation-level capacity for accommodating DER connected at the individual feeder level
What are the range of issues and costs for accommodating DER across the entire distribution system?	Provide better visibility to the specific issues that arise, where, and how often they might occur throughout the system
What amount of DER can be accommodated across my entire system?	Identify locations and aggregate DER for improved bulk system studies
When my feeder changes, how is hosting capacity impacted?	Streamlined methods repeated in an automated fashion for additional distribution configurations
What if different types of DER systems are deployed?	System-wide comparison of utility-class PV vs residential/commercial PV in terms of hosting capacity and issues that may arise
How can I visualize where DER impacts my feeder/system the most?	Visual interpretation of optimal vs non-optimal locations for DER
Is there a locational value to DER?	Value of solar to the utility
When and where smart inverters are needed?	Realizing smart inverters can mitigate many of the voltage-related issues caused by PV, feeders and locations where such capabilities are needed can be identified
What if I incentivized based upon location, how would I accomplish that?	Sensitivities regarding location/size can be investigated and system impacts rolled up to system-level

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3002004777 April 2015

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