21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

CIGRE US National Committee
2017 Grid of the Future Symposium

Hosting Capacity for Distributed Energy Resources on Distribution Feeders: A Case Study

H. LI, J. SMITH, M. RYLANDER
Electric Power Research Institute (EPRI)
USA

SUMMARY

This paper presents the application of a model-based hosting capacity analysis on the field demonstration sites/feeders of the Department of Energy – Sustainable and Holistic Integration of Energy Storage/Solar (DOE SHINES) project. A goal of the SHINES project is to evaluate the effectiveness of advanced inverter controls to integrate solar PV on distribution feeders. The Distribution Resource Integration and Value Estimation (DRIVE) method is used to determine the hosting capacity which is defined as the amount of DER that can be accommodated on a given feeder without impacting system reliability and power quality under existing control and infrastructure configurations. The hosting capacity results will be used to design the control and evaluate the effectiveness to integrate DER beyond normal limits.

KEYWORDS

Advanced Inverters, Distributed Energy Resources, DRIVE, Hosting Capacity, SHINES

hli@epri.com

Introduction

The exponential increase of DER on the distribution system has presented operational and planning challenges for utilities. The distribution feeder capacity to accommodate DER is limited by the feeder characteristics, DER locations, DER technology, etc. The amount of DER that can be accommodated on a given feeder without impacting system reliability and power quality under existing control and infrastructure configurations is referred to as hosting capacity [1]. The DER integration below the feeder's hosting capacity does not interfere the current distribution feeder operations. However, any DER integration exceeding the hosting capacity limit potentially poses adverse impacts on the feeder, such as overvoltage, voltage deviation, and thermal violations.

Hosting capacity varies with the DER location, feeder, and distribution system. Simple screens cannot provide the answers regarding the DER impacts on feeders and the associated hosting capacities. A model-based method is necessary for determining the hosting capacity. This paper presents the Distribution Resource Integration and Value Estimation (DRIVE) hosting capacity method [2] and its application to inform the DOE SHINES (Sustainable and Holistic Integration of Energy Storage and Solar PV) project.

Hosting Capacity

The impacts of DER on feeder increase with the growth of DER. Once the DER penetration reaches such a level that the power quality or reliability of the distribution system is adversely impacted, no more DER can be accommodated on the feeder without applying mitigation. Figure 1 illustrates how the hosting capacity can be determined at a node with an example of primary overvoltage. The blue dots indicate the maximum voltage anywhere on the feeder when the size of the PV system is increased at that node. The maximum feeder voltage is within the ANSI voltage limits for any PV penetration in the green region while the further increase of PV penetration triggers the overvoltage issue, causing maximum voltage beyond 1.05 Vpu. The rightmost boundary of the green region is the hosting capacity at that location for overvoltage issue. The node hosting capacity varies with location on the feeder and the feeder hosting capacity is range based on the node hosting capacities.

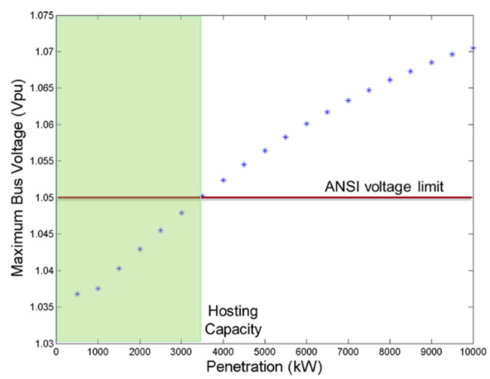


Figure 1. Example Calculating Hosting Capacity

The impact factors that are commonly considered as part of a typical DER interconnection study are listed in Table I. The four main categories are thermal, voltage/power quality, protection, and reliability/safety.

Table 1. Distribution Impacts Evaluated for Hosting Capacity

Thermal	Power Quality/Voltage	Protection	Reliability/Safety
Substation Transformer	Sudden (fast) voltage change	Relay reduction of reach	Unintentional Islanding
Primary Conductor	Steady-state voltage	Sympathetic tripping	Operational flexibility
Service Transformer	Voltage regulator impact	Element fault current	
Secondary conductor	Load tap changer impact	Reverse power flow	

Analysis Method

Hosting capacity is dependent on many factors typically available within feeder models. Using a model-based method, one can accurately determine the hosting capacity at the node-level (within the feeder) and then aggregate the hosting capacity up to the feeder-level. Detailed analyses iterate through thousands of load flows of the model with specific DER scenarios to determine impact. While the detailed study can provide accurate results, it is not computationally efficient. It can also take a significant amount of time to run through a limited set of impact factors for one feeder.

Distribution Resource Integration and Value Estimation (DRIVE), developed by EPRI, is a more efficient methodology to determine hosting capacity. While considering more impact factors than iterative detailed methods, it completes the analysis on one feeder in minutes. DRIVE utilizes very few load flows to extract all pertinent information needed to calculate DER hosting capacity. By extracting the characteristics of the distribution feeder model, the main variable (DER scenario) can be applied more efficiently. The DER scenarios consider centralized (single-site) and distributed (multiple-site) DER locations. Thousands of scenarios are examined on all potential locations, or "nodes", on the distribution feeder [2]. A simplistic illustration of a small subset of scenarios is shown in Figure 2.

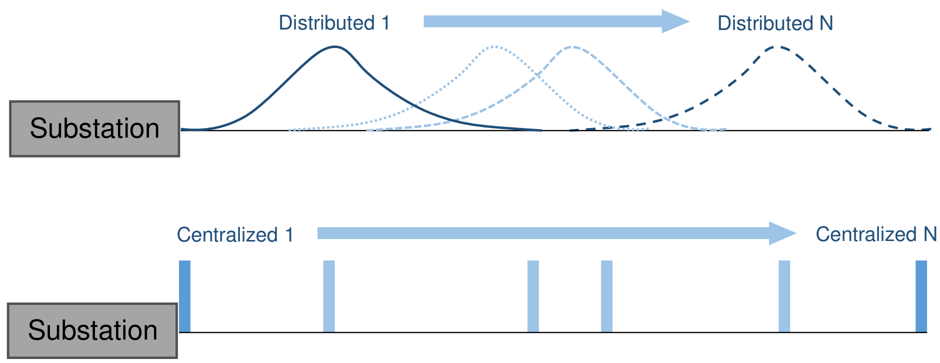
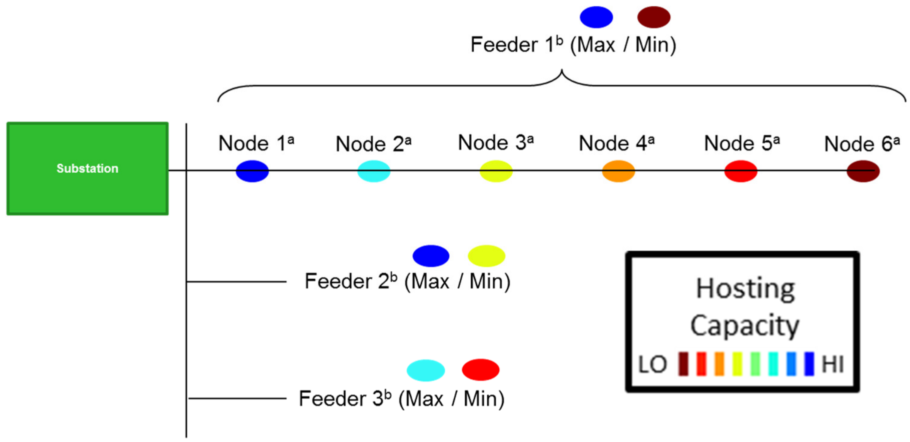


Figure 2. Subset of DER Scenarios Analyzed in DRIVE

These scenarios make up the basis of the DER impact analysis. Each scenario results in a node-specific hosting capacity for DER. The node is a point on the feeder between two line sections. Depending on the model, this may resemble locations in the field where the feeder branches or locations of power poles. For Centralized DER, a scenario's hosting capacity is based on DER at that location and does not consider DER at any other location on the feeder. For Distributed DER, a scenario's hosting capacity is depicted at the node where the DER is "centered" on the feeder and only considers DER at other locations based on the applied DER distribution. For both Centralized and Distributed DER, there are as many scenarios simulated as there are nodes on the feeder. Each scenario results in a hosting capacity value and therefore there are two hosting capacities at each node – one based on Distributed DER and another based on Centralized DER. The number of hosting capacity values then scales linearly with the number of distribution impacts considered.

A simple feeder example in Figure 3 illustrates hosting capacity at the node and feeder. In this example, one distribution impact is considered for centralized DER. The six nodes are each independently examined for the amount of DER that can be accommodated at that location. The colors indicate the resulting hosting capacity. The feeder hosting capacity is the range in node hosting capacity on the entire feeder. It is important to note that the feeder hosting capacity is not the summation of individual node hosting capacities. Each feeder can then be analyzed independently to determine their feeder hosting capacities.



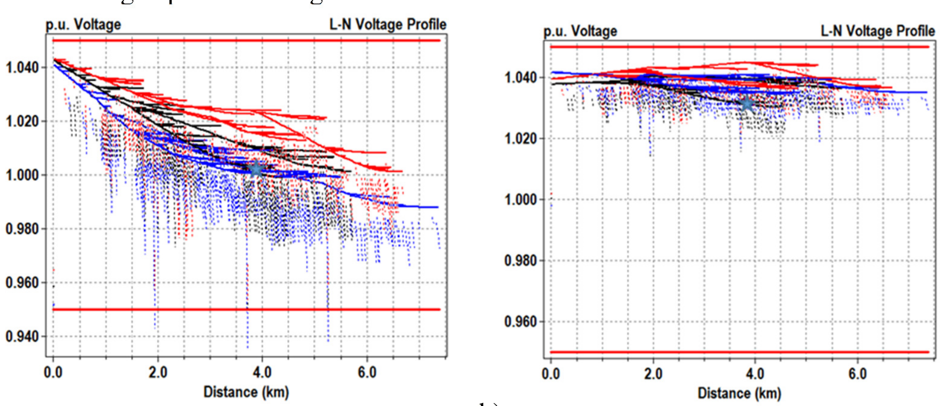
[a] Node Hosting Capacity is dependent on DER at other nodes. That shown above is based on DER only at the specified Node.
[b] Feeder Hosting Capacity is the Maximum/Minimum range of Node Hosting Capacity on the feeder.

Figure 3. Example of Node and Feeder Hosting Capacity for Centralized DER

Hosting Capacity Results of SHINES Demonstration Sites

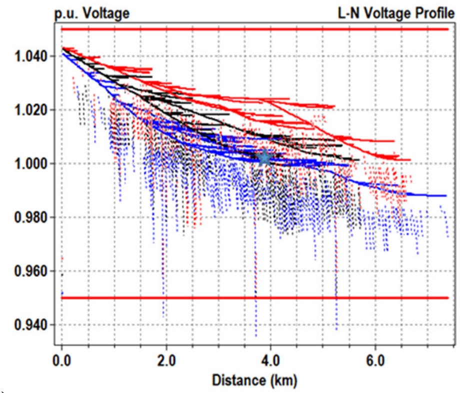
The ongoing SHINES project funded by the Department of Energy aims to develop the integrated control strategies for solar PV, energy storage, and load management to maximize the integration benefits. The Phase I base case study has been completed in which the demonstration site/feeder ability to accommodate solar PV was evaluated. The study will serve as the base case scenario to evaluate the benefit of the integrated control solution. The hosting capacity results on two demonstration sites/feeders are reported in this paper.

The voltage profile along the feeder that hosts one demonstration site are shown in a)

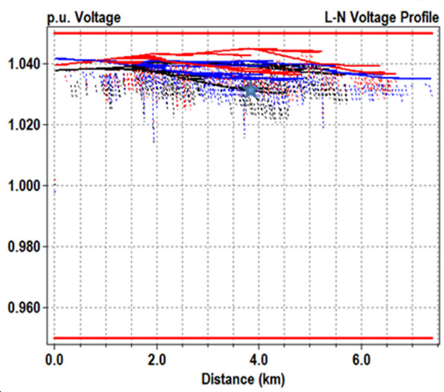


b)

Figure 4 for peak load condition and off-peak load condition. The demonstration site is at a single-phase

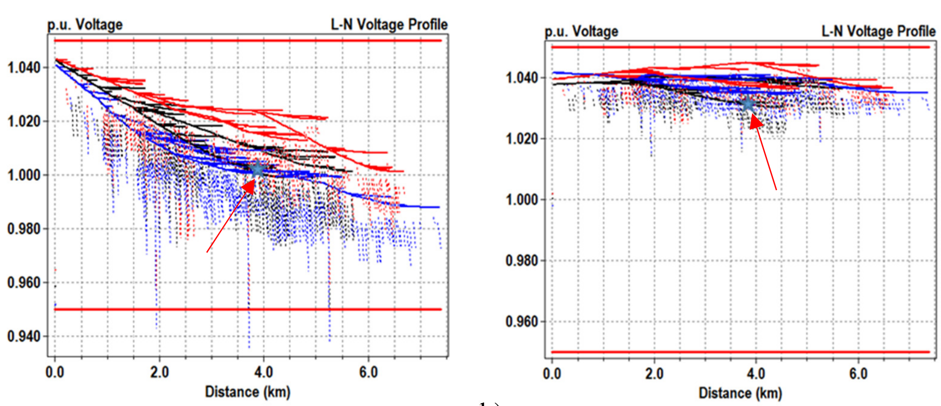


lateral and the voltages are indicated by the blue stars in a)



b)

Figure 4. There is very little voltage headroom in the off-peak load condition which suggests that overvoltage is a primary concern to the feeder's ability to host solar PV. The DRIVE analysis is applied on the feeder model to calculate the hosting capacity in both node level (demonstration site) and feeder level. The node level hosting capacity results are color coded on the circuit map as shown in Figure 5 a). As can be seen, the demonstration site is in the most constrained area. Table II lists the demonstration site hosting capacities for the impact issues considered. The overall demonstration site hosting capacity is limited to 30 kW due to the secondary overvoltage. It should be noted that the hosting capacities on secondary voltages issues are evaluated separately by simulating the local secondary voltage changes against the PV size increase. Secondary analysis is not yet included in DRIVE because secondaries are not typically modelled. In this project, only the demonstration site secondary information is available. At the feeder level, as seen in Figure 5 b), 0.17 MW can be accommodated at any node within the feeder while only the most optimal location can host up to 3.3 MW without causing violations based on primary voltage.



a) b)

Figure 4. Voltage Profile During a) Peak Load b) Off-peak Load

a) 

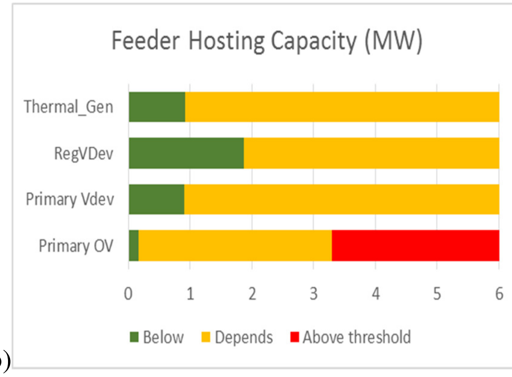
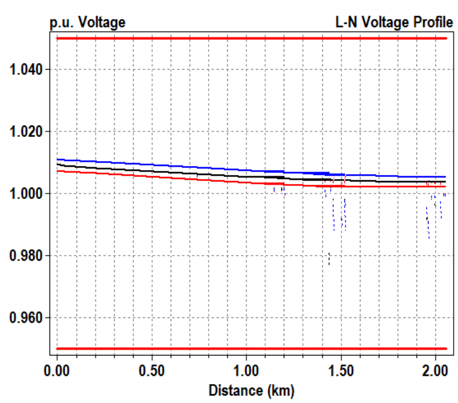
b) 

Figure 5. Hosting Capacity Results a) Node Level b) Feeder Level

Table 2. Hosting Capacities – Demonstration Site I

Issue	Hosting Capacity (MW)
Primary Over-voltage	0.17
Primary Voltage Deviation	0.9
Regulator Voltage Deviation	1.87
Secondary Over-voltage	0.03
Secondary Voltage Deviation	0.075
Thermal for Gen	0.92

The other demonstration site is on a dedicated college campus distribution feeder. As can be seen in Figure 6, the voltages are quite stiff. The hosting capacities results in Figure 7 a) confirms that voltage is not an issue at this site. The overall minimum demonstration site hosting capacity is limited due to potential thermal issues as shown in Table 3. Similarly, the feeder hosting capacity is limited by thermal issue shown in Figure 7 b).

a) 

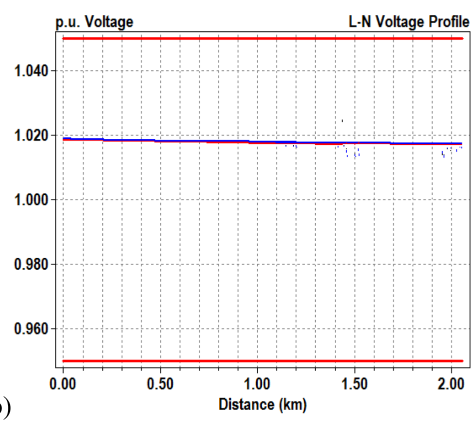
b) 

Figure 6. Voltage Profile During a) Peak Load b) Off-peak Load

a) b)

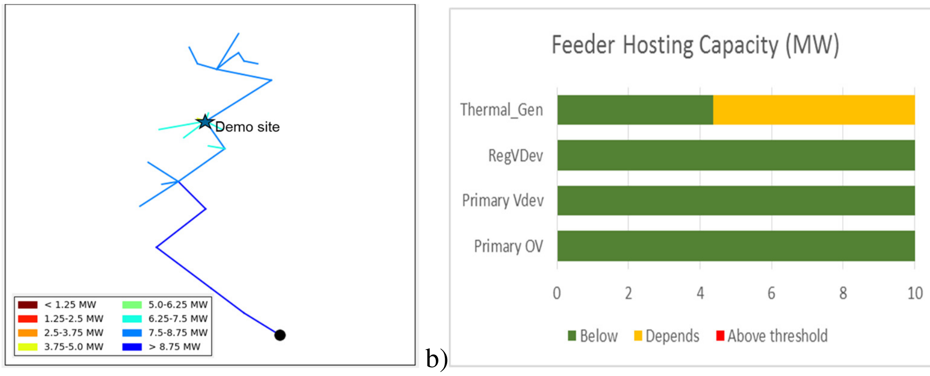


Figure 7. Hosting Capacity Results a) Node Level b) Feeder Level

Table 3. Hosting Capacities – Demonstration Site II

Issue	Hosting Capacity (MW)
Primary Over-voltage	10
Primary Voltage Deviation	10
Regulator Voltage Deviation	10
Secondary Over-voltage	10
Secondary Voltage Deviation	10
Thermal for Gen	8.68

Conclusions

DRIVE is effective in calculating hosting capacity to better understand the ability for a feeder to accommodate DER. The hosting capacities results on the two demonstration sites/feeders show that the distribution feeders have a unique ability to accommodate DER. The hosting capacity results will be used as the base case to design and evaluate the effectiveness of the advanced integrated control solution on the demonstration sites. For example, the integrated control at the studied site I should be designed to mitigate voltage and thermal issues. The effectiveness of the control design would mitigate potential DER induced violations and expand the feeders hosting capacity.

BIBLIOGRAPHY

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

[2] M. Rylander, "Distribution Resource Integration and Value Estimation," presented at the IEEE Photovoltaic Specialists Conference (PVSC), Portland, OR, 2016, pp. 1–5