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

CIGRE US National Committee
2015 Grid of the Future Symposium

Assessing Feeder Hosting Capacity for Distributed Generation Integration

D. APOSTOLOPOULOU*, E. A. PAASO, K. ANASTASOPOULOS
Commonwealth Edison Company
United States

SUMMARY

Driven by the declining prices and incentive programs related to renewable energy, there has been a substantial increase in the penetration of distributed generation (DG). With the increased penetration of DG, utilities are beginning to see impacts on their system, perhaps one of the most influential being the utility feeders' ability to accommodate DG. The amount of DG that a feeder may accommodate differs for each feeder and is influenced by the location and the size of DG. Thus, there is a need for a systematic determination of the actual level of DG that could be installed in a particular distribution feeder, i.e., its hosting capacity.

In this paper, a stochastic analysis was applied for determining the hosting capacity for DG. We report on the development of a framework simulation tool that provides the capability to quantify the effects of DG on feeder's performance and determine its hosting capacity by using distribution planning tools. We model the uncertainty in load levels and DG location and output. We deploy Monte Carlo simulation techniques to sample the random processes and calculate the expected values of various hosting capacity levels. We illustrate the capabilities of the proposed framework on a sample utility feeder. The results provide valuable insights on the effects of various DG scenarios and load level realizations on a feeder.

KEYWORDS

Distributed Generation, Hosting Capacity, Feeder Analysis, Stochastic Approach, Proposed Simulation Framework

*Dimitra.Apostolopoulou@ComEd.com

1. INTRODUCTION

The increasing adoption of distributed generation (DG) challenges the traditional planning and operations of utility distribution systems. These systems have been radial and had single directional power flows and protection schemes, whereas with DG the power flows can become bi-directional and impact the circuit protection and control schemes. The increase in DG penetration possesses many challenges to the utilities, perhaps one of the most influential being the utility feeders' ability to accommodate DG. This concept has been referred to as DG hosting capacity. Hosting capacity is defined as the maximum amount of new power production or consumption that can be connected without endangering the reliability or power quality for other customers [1]. Per this definition, the DG hosting capacity refers to the amount of DG that can be connected to the distribution system without negatively impacting the power quality or reliability. In terms of the DG hosting capacity, every distribution feeder is somewhat unique due to the countless combinations of voltage class, conductor type, feeder topology, customer behavior, loading, etc.

It is not until recently that the distribution utilities have begun to evaluate the DG hosting capacity in detail; there was little to no need to monitor DG on distribution feeders when the DG penetration levels were low enough to have negligible effects to the system. As DG penetration has kept increasing, utilities have begun to experience various problems such as over voltages and over currents. Federal Electric Regulatory Council (FERC) interconnection requirements for Small Generation Facilities (SGF), i.e., FERC Order No. 2006, allows a fast track process for DG units that are less than 2 MW in size when the DG on the feeder is less than 15% of the feeder peak load [2]. Based on the order, intensive analytical study for DG was not required as long as the aggregated DG on the feeder did not exceed the 15% threshold. The same 15% threshold was adopted in the IEEE Distributed Generation interconnection standard [3]. The screening threshold provides a first level estimate, but it is often conservative in terms of the actual level of DG that could be installed in particular distribution feeder. The threshold did not take into account the locational impact of the DG or the specific characteristics of each feeder. To capture impacts on the system through potential DG deployment scenarios, stochastic approaches have been adopted to take into account the uncertainty in the size and the location of potential installed DG units [4-8]. The key advantages of the stochastic methods include the overall application scalability through automated simulations and analyses. The stochastic methods are typically conservative as they tend to evaluate the DG hosting capacity for a feeder during minimum loading conditions.

In this paper, we discuss a simulation framework developed by a distribution utility to evaluate the DG hosting capacity of its feeders by utilizing commercial distribution planning software and high level programming language with Component Object Modelling (COM) interface. Instead of utilizing the conservative approach with minimum loading conditions, in the proposed framework we consider a stochastic loading model based on the historical data of the distribution feeders. The remainder of the paper is structured as follows: Section 2 provides the proposed simulation framework; Section 3 displays the uncertainty modelling utilized in this work; Section 4 details an illustrative study to demonstrate proposed concepts, and Section 5 concludes the study.

2. PROPOSED SIMULATION FRAMEWORK

The proposed framework is based on a steady-state analysis and emulates the integration of DG on a specific feeder to evaluate the effects of DG on the feeder's performance. In this section we describe the overall Monte Carlo procedure [9]. The simulation emulates the power flow on the feeder for various load and penetration levels. The modeling of these variable and uncertain quantities is in terms of continuous and discrete random variables respectively. These input random variables are mapped into the output random variables, which are the minimum and maximum hosting capacity of a feeder, through the power flow function. We provide a conceptual representation of such a mapping in Fig. 1. We carry out M number of simulation runs and estimate the output random processes. The number of simulation runs depends on the statistical reliability requirements specified for the estimation of the desired expected values.

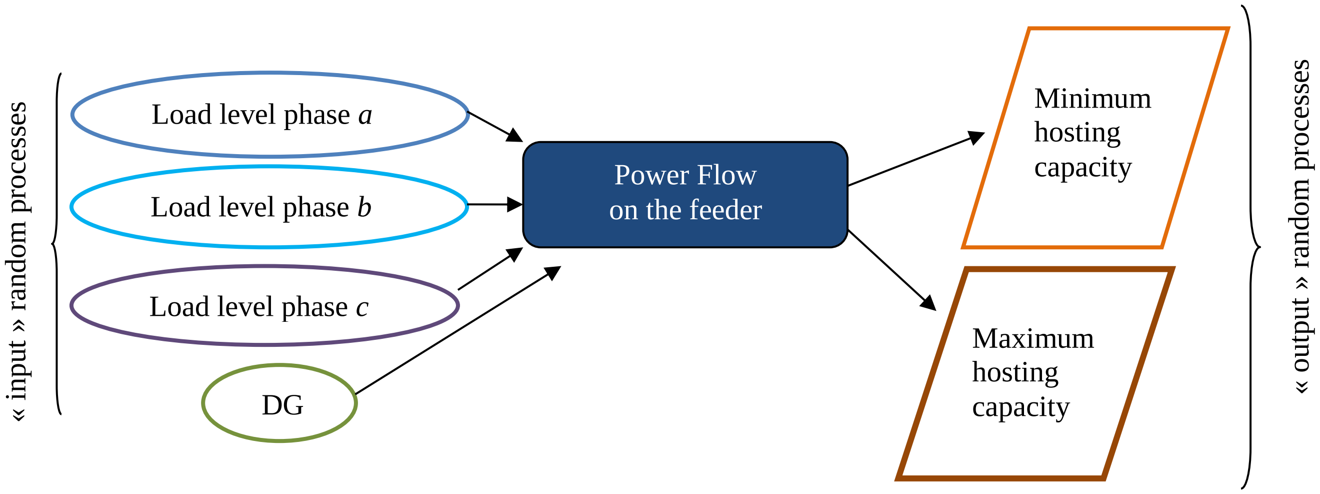


Fig. 1. Conceptual structure of proposed framework

In order to create a realization, we sample the load random variable and implement several DG scenarios, which are different in terms of location and size. The distribution feeder model consists of all primary power delivery elements from the substation transformer to the individual customer, and is modeled via the power flow process on a commercial planning software. The output of the power flow generates the voltage at each bus. We gather the maximum voltage for all the scenarios and penetration levels, and compare them with the ANSI voltage limit to determine which penetration levels in each realization might cause problems in the feeder [10]. The minimum hosting capacity refers to the penetration level where the first violation is observed. The maximum hosting capacity refers to the penetration level where all the maximum voltages exceed the ANSI voltage limit. At the end of the M simulation runs we obtain a probability distribution function (pdf) for the minimum and the maximum hosting capacity of a feeder.

In this paper, voltage is selected to be the monitoring criterion. However, there are other criteria that may be taken into consideration. For instance, thermal loading limits, phase voltage deviations from average and more may be included in the proposed framework.

3. UNCERTAINTY MODELING

The modeling of the input random processes is very important, since it affects the outcomes of the proposed simulation framework. We have developed an approach to model the sources of uncertainty associated with DG and load levels at a feeder for all the three phases in a high level programming language with Component Object Modelling (COM) interface.

3.1 *Distributed Generation*

The effects of DG on a feeder’s hosting capacity are affected by its location as well as its output. In order to accurately assess the DG impacts on the distribution systems and capture the uncertainty in the size and the location of potential DG installations, we have adopted a stochastic approach through several DG deployment scenarios.

For the stochastic analysis, the DG is assumed to operate at the rated AC power output; such an assumption is reasonable, since it is vastly used in transmission and distribution planning [7]. Moreover, the customer service point is considered to be the interconnection point of each individual

DG. In this regard, the installed DG size is determined by the number and class of customers. We take into account small-scale DG, so the customer classes that are incorporated are residential and commercial.

For a given load level multiple scenarios and penetration levels of DG are developed to evaluate a feeder's hosting capacity. For each scenario, we start with zero penetration of DG, randomly select feeder buses where a DG is installed, and solve the power flow. As penetration increases for a specific scenario, further DGs are accrued in addition to those existing in the same scenario at the previous penetration level. For each load level we calculate the voltages at the buses for various penetration levels and scenarios. Penetration is increased until the maximum capacity of DG is reached.

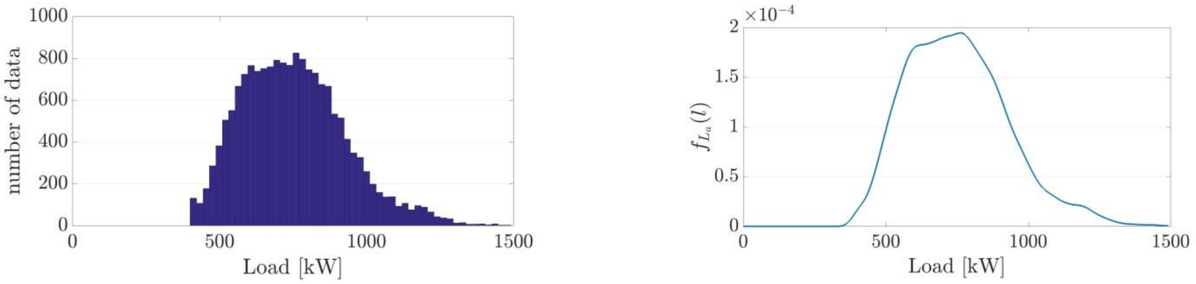
3.2 *Load Level*

The load level is used as an input in the proposed simulation framework, as depicted in Fig. 1. The random variable of load L_i for each phase $i = a, b, c$ follows a pdf that can be constructed based on historical data of the load at a feeder for each phase. Thus, historical data of the load for each phase are collected to build an empirical pdf. However, the result of the pdf has the form of a step function due to the finite amount of data. In order to smooth the pdf we use the kernel density estimation (KDE) method [11]. In order to produce each realization that is fed into the power flow, as shown in Fig. 1, we need to combine the three pdfs of the loads at the three phases. To this end, we build a joint pdf $f_{L_a L_b L_c}(l_a, l_b, l_c)$ of the three loads by assuming that the random load variables at each phase L_a, L_b, and L_c are independent (e.g., [12]).

We use the joint pdf to obtain a realization of the load at each phase. Since there are only available load measurements at the substation level, we built a joint pdf for each phase at the substation level and distribute the realization of the load to each bus at each phase based on its number of customers.

4. ILLUSTRATIVE STUDY

We performed extensive testing of the proposed framework to validate the results. In this paper, we illustrate the application of the framework with a representative utility feeder, which contains 366 nodes and 365 lines. We collected historical load data over the past two years of the representative feeder. The minimum load for phase a, L_a, at the substation level was 400 kW, and the maximum load was 1,491 kW. In Fig. 2, we depict the histogram and pdf based on the KDE of the load random variable L_a. We notice that the pdf in Fig. 2b provides us better information for all levels of loads than the histogram given in Fig. 2a.



(a) Histogram of L_a (b) Pdf of L_a

Fig. 2. Load at phase a, L_a

We increase the DG penetration as described in Section 3.1 and obtain the maximum voltage for each realization. For example, in Fig. 3 we show the various voltage levels for different penetration scenarios for load level 560 kW at phase a, 600 kW at phase b, and 480 kW at phase c. For DG with a size less than 800 kW, all penetrations are acceptable regardless of location. For penetration levels from 800 kW to 3,000 kW, we notice from Fig. 3 that there are some violations and that the location of DG plays an important role. Finally, for penetration levels greater than 3,000 kW, we notice that all possible locations violate the voltage limits defined by the ANSI standard. As it can be seen, the same amount of kW of DG installed in the feeder might have different results based on the location of the DG.

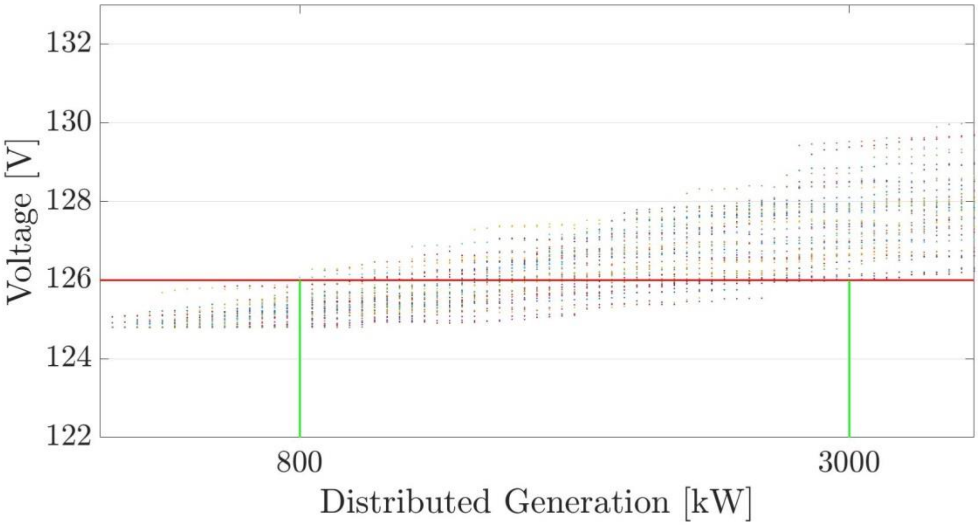


Fig. 3. Maximum voltage for various penetration levels and locations

We run 100 Monte Carlo simulations and calculate the minimum and the maximum hosting capacity for each realization. We depict in Fig. 4, the pdfs of the minimum and maximum hosting capacity. Based on these values, utilities may decide what confidence level is acceptable and how much risk they are willing to undertake. In this specific example, a more conservative approach would be to allow a penetration of 2,000 kW.

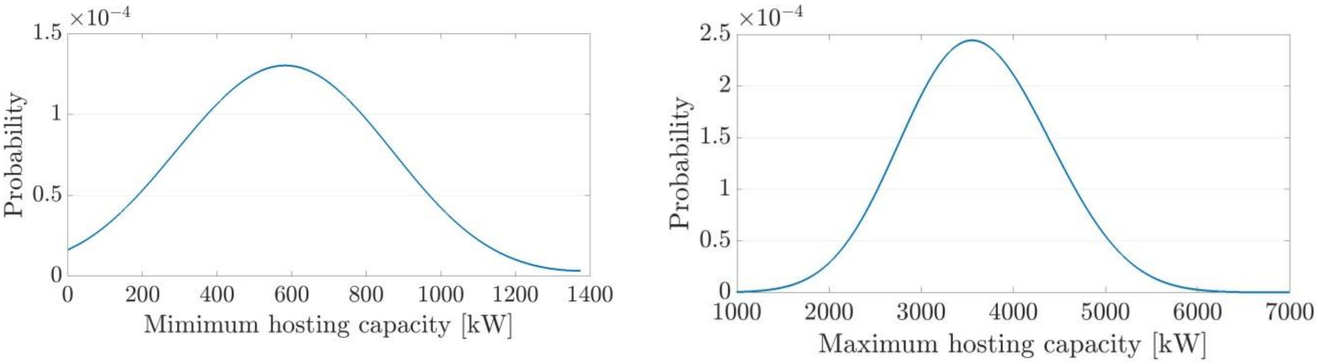


Fig.4. Pdfs of minimum and maximum hosting capacity

If the 15% rule was used in this specific example then the hosting capacity would be 671 kW. A stochastic method that evaluates the hosting capacity of a feeder during minimum load conditions determines that the minimum hosting to be 450 kW and maximum hosting capacity 3,000 kW. Thus, we may see that when we only take into account the minimum loading conditions the minimum hosting capacity is less than the one provided from the 15% rule. Our proposed framework provides more realistic results as depicted in Fig. 4. Therefore, a more detailed approach as the one described in this paper is beneficial for utilities' planning.

5. CONCLUSION

In this paper we presented a stochastic simulation framework that can determine the hosting capacity of a feeder for DG integration. Our approach makes detailed use of realizations of the random variables considered in the adaptation of Monte Carlo simulations. In this regard, the uncertainty sources are represented explicitly. The proposed framework has various applications. Besides determining the hosting capacity of a feeder, it may be used by utilities, e.g., to identify ideal locations for DG installation, so that necessary feeder upgrades may be minimized.

In the illustrative study section, we showed that the proposed approach provides more realistic results than other heuristics approaches. In addition, we described the process at every step, from the determination of the load levels, to specific realizations, and finally to the pdfs of the minimum and maximum hosting capacities. Future work includes taking into account other monitoring criteria in the analysis and to differentiate between the various sources of DG, e.g., wind or solar, and take into account their specific characteristics.

BIBLIOGRAPHY

[1] M. H. J. Bollen, Y. Yang, and F. Hassan, "Integration of distributed generation in the power system - a power quality approach," (13th International Conference on Harmonics and Quality of Power, 2008, pp.1-8)

[2] Federal Electric Regulatory Council, FERC Order 2006 (Issued May 12, 2005, p. 9)

[3] “IEEE Application Guide for IEEE Std. 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems,” (IEEE, 2008, pp. 1-217)

[4] Electric Power Research Institute, “Alternatives to the 15% Rule: Modeling and Hosting Capacity Analysis of 16 Feeders,” (Palo Alto, CA, 2015, pp. 1-122)

[5] Electric Power Research Institute, “Impact of High-Penetration PV on Distribution System Performance: Assessment of Regulation Control Options for Voltage Mitigation”, (EPRI Palo Alto, CA, December 2014, pp. 29-42)

[6] J. Smith, M. Rylander, L. Rogers, and R. Dungan, “It’s all in the plans: Maximizing the Benefits and Minimizing the Impacts of DERs in an Integrated Grid," (IEEE Power and Energy Magazine, vol.13, no.2, March-April 2015, pp. 20-29)

[7] Electric Power Research Institute, “Stochastic Analysis to Determine Feeder Hosting Capacity for Distributed Solar PV,” (EPRI, Palo Alto, CA, December 2012, p. 18)

[8] L. Dow and J. Romero Aguero, “Integration of PEV and PV sources into the Electric Distribution Systems”, (IEEE Power & Energy Society General Meeting, Detroit, MI, 2011)

[9] G. Fishman ,“Monte Carlo, Concept, Algorithms, and Applications” (Springer, 1996, pp. 145-155)

[10] PacifiCorp, “Voltage Level and Range”, (Engineering Handbook, February 2007, p.2)

[11] J.-N. Hwang, S.-R. Lay, and A. Lippman, “Nonparametric Multivariate Density Estimation: A Comparative Study,” (IEEE Transactions on Signal Processing, vol. 42, no. 10, October 1994, pp. 2795-2810)

[12] A. W. Drake, “Fundamentals of Applied Probability Theory,” (McGraw-Hill, 1988, pp. 103-112)