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Comparative Assessment of Hosting Capacity Analysis Methods: Industry Best Practices and Standardization Framework

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SUMMARY

The growing interest in deploying Distributed and Renewable Energy Resources (DERs) driven by grid modernization and decarbonization of electric industry have challenged utilities' distribution planning practices. The overall goal of advanced planning processes, introduced in recent years, such as Hosting Capacity Analysis (HCA) is to assess the capacity and availability of the grid for hosting various DER technologies and guide the DER deployment project in areas that can support various capacity and reliability enhancement projects. Utilities have started implementing HCA and utilizing the results as an integral part of planning for DER application evaluation and prioritizing distribution capital investments. In addition, several state and provincial statutes and utility regulators have mandated the needs for publishing data and frequently updated reports on the hosting capacity of distribution systems; in order to encourage higher DER penetration in the system.

The objective of this paper is to provide a summary of industry best practices on HCA implementation methods, highlighting the main drivers, impact assessment approach and key challenges. Based on the gaps identified in the existing methods, the paper outlines targeted enhancement and advancements expected in future HCA based tools, in both commercial and utility home grown methods.

Furthermore, the paper provides an assessment of the needs for standardization of the HCA approaches. Standardization effort will be towards identifying and applying a unified framework in the core aspects of implementation, results publication and re-assessment of limits and outcome, which results in great benefits for utilities as well as developers.

KEYWORDS

Distributed Energy Resources (DER), Distribution Networks, Hosting Capacity Analysis, System Planning, Grid Modernization, Advanced Inverter Functions (AIF)

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1. INTRODUCTION

Hosting capacity analysis (HCA) is an analytical tool that helps quantify and visualize the grid ability for integrating DERs. Although presently there is no standardized definition for hosting capacity, the industry has adapted a definition suggested by Electric Power Research Institute (EPRI) stated below [1]:

"Hosting Capacity is the amount of DER that can be accommodated in the selected part of a distribution system – either at a node or collectively at feeder level - without adversely impacting power quality or reliability under current configurations and without requiring infrastructure upgrades."

The primary goal of HCA is to assess the capacity and availability of the grid for hosting various DER technologies. The quantification process is based on a series of operational criteria including thermal loading, voltage/power quality and protection coordination to ensure reliability and integrity of the grid. The analysis outcome supports both utilities and DER owners (or DER developers) in the following areas:

- Utility planners can use HCA as part of advanced distribution planning approach to identify and prioritize grid enhancement projects that can increase DER adaptation rate,
- The published results can provide supportive information for stakeholders and decision makers (regulatory agencies, utilities, and DER owners) to guide DER deployment projects in areas that would benefit the grid capacity and reliability enhancement.
- HCA provides more accurate and comprehensive screening results for the interconnection application evaluation in comparison to the conventional rule-of-thumb based screening approaches. For specific interconnection application, HCA uses system characteristics to analyze the boundary conditions of the grid for the given DER location, DER size and technology.

Based on the above definition, HCA should be able to evaluate marginal system conditions that are considered unacceptable performance by applying planning criteria under all operating points. To achieve reliable HCA outcome, verified distribution planning models for power flow analysis along with historical/statistical information about load profiles and generation adaptation patterns are required.

Several papers have discussed the HCA of distribution networks based on various boundary conditions and methods [2–6]. In general, three methods for Hosting Capacity calculation are commonly used by industry or as part of commercial software tools, namely:

- Stochastic Hosting Capacity Assessment Tool
- Iterative - Integrated Capacity Analysis, or ICA Tool
- Streamlined - Distribution Resource Integration and Value Estimation (DRIVE)[1] Tool

This paper provides a summary of industry best practices on implementing hosting capacity analysis (HCA) methods based on information captured from a series of interviews and surveys conducted among North American utilities and commercial HCA software providers. The HCA methods currently in practice are examined and compared from different perspectives, including methodologies applied in DER modeling and impact assessment, level

[1] DRIVE is the proprietary tool of Electric Power Research Institute (EPRI).

of complexity in analysis, data granularity, automation schemes used for processing data and in study execution, as well as measurement & verification (M&V) processes incorporated to verify the analysis outcome with respect to real-world observations.

The rest of this paper is organized as follows: Section 2 provides a summary of industry best practices on implementing HCA methods and targeted enhancement and advancements expected in future HCA tools. Section 3 outlines the existing gaps and challenges utilities are facing to implement the HCA methods. Several key factors currently excluded from the common HCA methods are identified, examined and their potential impact on the analysis results are discussed. The paper concludes with an assessment of the needs for standardization of the HCA approaches for identifying and applying a unified framework in the core aspects of implementation, publication of results and re-assessment of limits and outcome.

2. INDUSTRY BEST PRACTICES

Many utilities in North America (NA) have already implemented HCA methods and publishing results in form of heatmaps or system constraint tables for public use. Remaining utilities are either in the process of finalizing the methods and results to be included in their next generation of advanced distribution planning approaches or implemented the HCA methods only for internal use. Although HCA may have been initially triggered by the need for added transparency for DER developers and customers to identify distribution systems available capacity for accepting DER, once implemented, HCA has proven to immediately become an integral part of distribution planning and DER interconnection application processes.

Availability of HCA results for public use are normally driven by state/regional regulatory mandates. Utilities may also choose to publicize HCA data proactively in certain regions that medium to high DER penetration is expected, or some level of data will be reported on system limits for areas that T&D infrastructure constraints are becoming the limiting factor. However, the general concern with publicizing hosting capacity data, in one hand, is related to the clarity or interpretation of information. On the other hand, there is concern with quality of data and how up to date is the published results, considering dynamic nature of distribution system operations and status of new expansion projects. For those reasons, the advanced HCA methods is expected to include extensive level of automation and data verifications to facilitate frequent system level re-analysis and updating publicized hosting capacity data.

2.1. Baseline for HCA Implementation

The baseline for an HCA implementation can be discussed from two aspects: timeframe of implementation, and tools/methodologies utilized.

The early adopters of HCA have typically used in-house developed tools for implementing the methodologies and conducting most of the analysis. In this approach, a utility would only utilize a planning software tool as a power flow engine for obtaining voltages and power flow related data per analysis step. However, as the software tools are advancing and commercial tools with powerful HCA modules are emerging, transitioning to commercial tools may be on the roadmap. The primitive methods used by early generation of commercial tools or the simplifying assumptions applied in the process may have been a key deciding factor in developing in-house tools that more closely follow the utilities planning considerations.

From methodology perspective, the iterative or streamlined methods are available through commercial tools, or through a combination of in-house developed tools (for process automation) and commercial tools (which are used as a computational engine). Example software tools and methods in use by NA utilities are:

- Python scripting in conjunction with CYME software tool,
- Scripting methods with Synergi planning model,
- Synergi plus EPRI DRIVE tool,
- GridLAB-D[2] for the network model creation and EPRI's DRIVE tool for the HCA analysis,
- Entirely in-house tools with provision to migrate to a commercial tool

Some utilities have also developed or are working toward implementing more advanced methodologies such as stochastic methods or incorporating geospatial and societal related data for more accurate determination of DER (generation) mix and expected penetration governed by DER types and available lands. In addition, it was noted that stochastic methods are of high interest by utilities, but still in early stages of development by most commercial software providers.

2.2. Boundary parameters and system conditions

HCA is normally examined for specific operating conditions of the system that are listed in Table 1. The operating conditions define number of study cases and complexity of analysis.

Table 1. Basic and Advanced Study Conditions used in HCA

Basic Operating Conditions and Study Cases	Additional Operating Conditions and Cases Analyzed
• Minimum daytime load • Maximum 24-hour load • Inverter based DER only cases • Mix of inverter based and rotating machines	• Contingency cases (reduced fault current) • Feeder reconfiguration (load transfer for abnormal condition) • Load growth

Most utilities use minimum and maximum feeder loading for the HCA. The analysis may consider the change in the system configuration due to utilizing typical distribution automation schemes. For 34 kV systems, some utilities will apply contingency cases that could be in place for abnormal condition, which may further limit the DER hosting capacity.

The boundary parameters that are used in utility HCA approaches are mainly voltage and power flow parameters. A few NA utilities incorporate advanced parameters such as protection and harmonic assessment in the study cases. Table 2 provides two categories of boundary parameters based on the utility survey: 1) commonly applied parameters that are used by most utilizes, and 2) advanced parameters. Voltage and thermal limit impact analysis are among the common parameters utilized in all HCA process. However, harmonic analysis,

[2] http://www.gridlabd.org/

as an example, or protection coordination evaluation are rarely incorporated, but they are on development roadmap for most utilities.

Table 2. HCA Boundary Parameters

Commonly Applied Boundary Parameters	Advanced Boundary Parameters
• Thermal limits (overloading of feeder equipment or conductors) • Voltage limits (steady-state) • Rapid voltage changes (dynamic variations) • Impact on voltage regulators and tap changers operation • Reverse power flow	• Protection ➢ Reach reduction ➢ Sympathetic tripping • Harmonics ➢ Individual harmonics ➢ THD/TDD

Although some HCA tools have the capabilities to include protection and harmonic boundary parameters, most utilities do not currently check for them in the analysis. For protection related parameters or to incorporate impact on secondary systems, the limiting factor is lack of data and proper system representation in the planning model databases. For instance, most planning tools only have primary system models (medium voltage) represented. The information about protection schemes and settings are also not included in the planning models, which limit how much protection coordination and sensitivity analysis can be performed as part of HCA.

3. GAP ANALYSIS IN CURRENT PRACTICES AND FUTURE ENHANCEMENTS

Based on survey of current HCA practices in North America, this section investigates identified gaps and potential future enhancements that are either in utility roadmaps or as part of future considerations.

3.1. Gap Analysis

Current industry practices followed for HCA vary widely based on the jurisdiction and regulatory requirements as well as the utility system characteristics and HCA implementation stage. The assessment of the gathered data or publicly available information reveals following gaps and challenges in both commercial and utility in-house HCA methods:

- Accounting for PV net-metering and customer PV systems that are not mapped to the GIS and planning tools, which changes the load.
- Lack of automation in the commercial tools to coordinate the process of data import, time series analysis, and preparing reports.
- Incorporating the latest revision in standards such as the recent introduction of IEEE 1547-2018 and a revision to CSA C22.3 No.9 interconnection standard. As an example, currently Advanced Inverter Functionalities (AIF) and their supporting role in increasing hosting capacity is not incorporated into the existing HCA implementations.

- No standardized or established methodology for applying M&V processes in current tools or processes to validate HCA results.

3.2. Future Enhancements

Although HCA advancements are utility dependent and follow the local utility and regulatory environment, several areas of enhancements are identified for existing HCA methods, as shown in Figure 1.

1) Data Integrity and process automation
    a. Interfacing with different databases and data sources for providing a comprehensive data set to HCA analysis tools
    b. Establishing methods and approaches for data integrity verification and confirmations of results through the concurrent implementation of alternative methods,
2) Model Enhancements
    a. Expanding on boundary parameters and system conditions that are evaluated through HCA, such as addition of protection analysis and technology mix (e.g. solar plus storage:
        i. Protection (coordination, selectivity) and harmonics
        ii. Incorporating distribution automation schemes to account for re-configuration
        iii. Analytical methods for including secondary networks
        iv. Providing user selection for identifying various combinations (mix) of technologies in % of penetration expected for HCA such as 50% PV, 30% EV, 20% Synchronous gen for each analysis.
3) Process Improvement
    a. Enhancing the speed of calculation to make them fast enough from computational aspects to repeat the analysis more frequently when the system changes occur, even though underlining assumptions may make the results more conservative.
    b. Increasing level of automation in the HCA processes for importing data, building models, and exporting results to other tools
    c. Evaluating the impact of advanced mitigation solutions such as advanced inverter functions and non-wires alternative on enhancing hosting capacity limit and incorporating feasible approaches based on new technological capability (e.g. distribution automations) as optional enhancement cases.
4) Standardized M&V Process
    a. Introducing more precise analysis and result verification approaches, while maintaining proper level of clarity and simplicity on interpreting results for public,

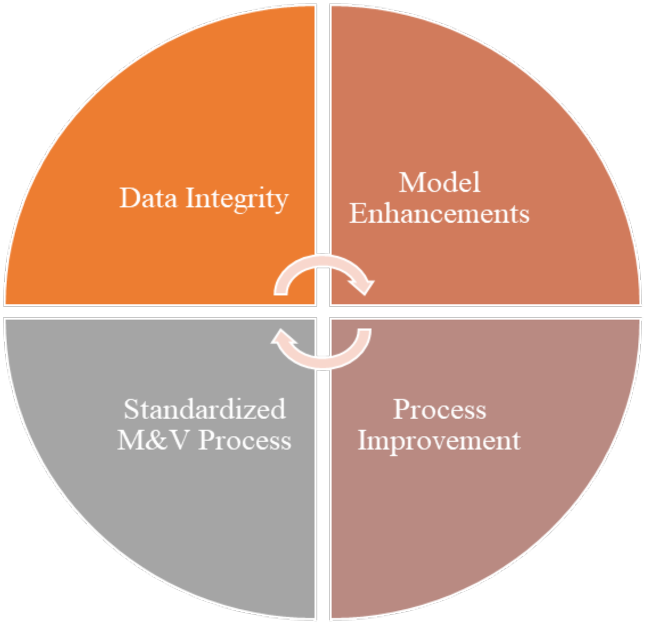

Figure 1. Areas of Future Enchantements for HCA

These enhancements will help utilities with:

- More accurate and realistic HCA results based on the data availability, model enhancement and process improvement. The results will be further verified through M&V process; if large deviations are observed, the root causes should be identified and addressed in the cycle of overall process improvement,
- More frequent updates of the HCA results through streamlining the processes for model updates and input data integration, as well as increasing the level of automation in performing the analysis,
- More strategic planning inputs on potential mitigation solutions based on new technological capabilities such as Advanced Inverter Functions (AIFs).

It should be noted that several utilities are working toward implementing more advanced methodologies and analytical features in the HCA tools either in house or through collaboration with software vendors. New developments are focused on stochastic methods or incorporating geospatial and societal related data for more accurate determination of DER mix and expected penetration by DER types and available lands.

4. Standardization Framework

Standardization effort will be towards identifying and applying a unified framework in the core aspects of implementation, results publication/ visualization methods and re-assessment of limits and outcome.

Utilizing an industry standard for evaluating Hosting Capacity methods can benefit both utilities and developers. The key advantages include a better interpretation and utilization of the published data in identifying DER investments and applying for DER interconnection. Furthermore, standardization aims at promoting innovation in commercial tools and streamlining evaluation and comparison of the outcome from various methods.

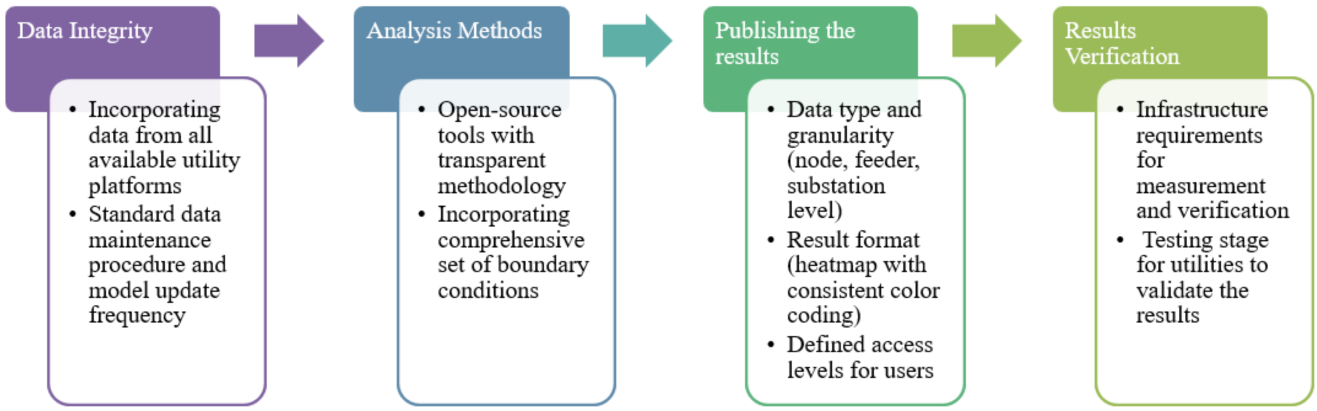

Figure 2. HCA Standardization Considerations

Figure 2 summarizes some of the considerations that will support streamlining HCA within North American utilities.

Data integrity: Currently, utilities use data from different platforms as input to their HCA tool. Utilizing similar data platforms as a base ensures the results of analysis are comparable and heatmap interpretation is consistent. Furthermore, implementation of a standard data update and maintenance procedure offers more confidence in the level of data accuracy and integrity.

Analysis methods: An open-source tool (e.g. introduced by National labs) with a transparent analysis approach can facilitate faster adaptation into a standard method by utilities. The applications of such tool will remain private and specific to each utility. Providing a comprehensive set of boundary conditions also enables utilities to more confidently utilize the HCA tool and publish more accurate results as applicable.

Publishing results: One of the key areas of standardization is the type and format of publishing data. A standard approach in terms of what type of data at what precision and granularity to provide; the publishing format and the access level creates a unified interpretation of the results amongst the users and clarifies use of heatmaps as a common tool for publishing data.

Results verification: Standardizing the set of measurement requirements and verification approaches supports the overall uniform framework for HCA. Defining a test stage for data collection and then verification procedure helps with identifying any gaps that needs to be addressed in the process.

5. Conclusions

Survey of NA utilities approaches toward current implementation and future advancement of HCA approaches have outlined the needs for standardization of the HCA approaches. Standardization effort will be towards identifying and applying a unified framework in the core aspects of implementation, results publication and re-assessment of limits and outcome. Example areas of standardization includes more clear methods of visualization and demonstration of data inform of heatmaps as a common tool for publishing data, increasing the quality of assessment and accuracy for various DER technologies. Increase in DER penetration will also result in implementing stochastic HCA methods to facilitate complex analysis incorporating the resource/land availability and technology adaptation style by customers. Including advanced inverter functionaries in the analysis to evaluate mitigate solutions for adverse impact of DERs in critical areas of the grid will be required to further enhance grid accessibility in support of decarbonization of the electric industry.

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