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Lessons Learned from Performing an Integration Capacity Analysis (ICA)

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SUMMARY

In September 2017, POWER Engineers Inc. completed a hosting capacity analysis project using Eaton Corporation's commercially available Power Engineering Distribution Software (CYME) hosting capacity module, Integration Capacity Analysis (ICA), for Portland General Electric (PGE) in Portland, Oregon. The objective was to perform the analysis on one substation containing seven feeders as a pilot project to identify the capabilities and potential scalability of using CYME's ICA tool system wide. The model and analysis included both the primary and secondary networks of each feeder under minimum and peak loading conditions. CYME's ICA module utilizes both an iterative approach and heuristic calculations to calculate hosting capacity at all nodes. This is unlike CYME's EPRI DRIVE module, which applies a streamlined approach using only heuristic approximations to calculate capacity at all nodes.

The results of the study revealed, in some cases, long simulation run times and troubleshooting to verify results are realistic to be the primary challenges when using CYME's ICA module to simulate hosting capacity on large systems. Due to the computationally intensive iterative method approach, the way the feeders are modeled and the simulation parameters chosen should be thoroughly considered because of the larger impacts these items will have on the simulation time and result accuracy. If system wide analysis using ICA is to be performed, then there are several lessons learned that can help future hosting capacity studies by reducing the overall study run time and obtaining verifiable results. Presented in this paper are the findings of this hosting capacity study regarding the current capabilities and lessons learned for future system wide implementation.

KEYWORDS

DER, Hosting Capacity Analysis, Integration Capacity Analysis, CYME, lessons learned, iterative method, streamlined method, stochastic method, lessons learned

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INTRODUCTION

Across the United States, utilities are experiencing an increasing number of distributed energy resources (DER) installed on the grid and customer driven interconnection requests to the point where planning must be incorporated to guide DER integration. Motivated mainly by DER technology advancements, increased DER adoption by the public, and state or federal policies supporting renewable energy goals; it has been recognized that it will be beneficial to the utilities, stakeholders, and regulators to begin integrating DER into resource planning and transmission planning before the amount DER becomes too much for the grid to support.

Hosting Capacity is the amount of DER that can be connected to the grid without negatively affecting power quality or reliability and without requiring system improvements under existing configurations. A hosting capacity analysis (HCA) generates a location specific map of the hosting capacity at each node studied which provides information for utilities, regulators, and customers to be more efficient and make cost effective decisions when interconnecting DER.

The three accepted analysis methodologies – streamlined, iterative, and stochastic – each have their own advantages and trade-offs in accuracy, simulation run time, and capabilities to simulate different scenarios. There have been multiple hosting capacity pilot projects using each method performed by utilities throughout the United States; however, no one method or software has been fully accepted as the best method or tool for calculating hosting capacity. Therefore, further investigation and improvements in these methodologies are warranted to improve hosting capacity integration with planning and to provide reliable data for utilities, regulators and customers to make intelligent choices for installing DER on the grid [1][2][3].

HOSTING CAPACITY METHODS

The three common methodologies that have been applied to most hosting capacity analyses performed to date consist of either a streamlined, iterative, or stochastic approach. Each methodology has its own trade-offs which make it better suited for different use cases such as streamlining the interconnection process, enabling more robust and granular distribution system planning, or providing locational benefits of DER's through multiple scenario analyses [1].

The streamlined method uses a set of algorithms for each defined power system limitation to approximate DER capacity at each node. By performing a single initial power flow and a short circuit analysis, the baseline initial conditions of the circuit are then fed into software which uses a set of simple equations to evaluate the hosting capacity at each node. The equations are based on a full set of criteria and algorithms including thermal loading, resistance, voltage limits, protection, and safety limits. The ability to use simple equations and algorithms allows faster computations on large systems [2].

The iterative method performs power flow and short circuit simulations iteratively while increasing DER at each node individually to check for new or worsened violations with thermal, voltage, protection, safety criteria. The number of iterations required can become quite computationally intensive which can result in long simulation run times on larger networks. There is greater confidence in the accuracy of the iterative method results, especially on more complex circuits [2].

The stochastic method analyzes the existing distribution system to obtain initial conditions, and then DER is added to the system at randomly selected locations along a feeder and evaluated for any negative effects. The results are given as a hosting capacity range that corresponds to the minimum capacity that could result in a violation and the maximum capacity that will in high confidence result in a violation. Using this method, there is less computation time than the iterative approach, but it does not provide the same detail or accuracy as the streamlined or iterative methods do [1].

Different uses of analysis results, such as streamlining the interconnection process, integrating DER into planning, or utilizing DER locational benefits will typically drive the selection of the methodology and software. PGE models their distribution system in CYME (Version 8.0 Rev 4 was used for this study) so it was advantageous to use CYME's hosting capacity software module. The ICA module, using the iterative method, was chosen to consider the effects of DER on the network being studied while still achieving accurate results. CYME has recently introduced a new hosting capacity module known as EPRI DRIVE which uses the streamlined methodology; however, this was not available at the time of this study.

ASSUMPTIONS, PARAMETERS, AND LIMITING CONSTRAINTS

The system studied for this project included one substation, with three substation power transformers with load tap changers (LTC); seven feeders with a line-to-line voltage of 12.47 kV; and an entire secondary customer network of 240 V line-to-line. The new DER simulated was assumed to be photovoltaic (PV) with the DER parameters were chosen to match typical industry values. Table 1 shows the parameters used and Table 2 shows the constraints used in CYME's ICA for this study. The thermal loading, voltage limits, and voltage variation (flicker) were defined to PGE's preferences; however, the constraints of reverse power flow, reduction of reach, and sympathetic tripping were decided upon after further testing on how these constraints limit the results. PGE wanted to limit the hosting capacity if there was any reverse power flow onto the transmission system so reverse power flow was set to 0%. The protection reduction of reach and sympathetic tripping pickup security factors were also set to 0% to not displace the pickup in order to stop the study if any reduction of reach or sympathetic tripping occurs.

During the study, the DER iterations were simulated up to a defined limit set by the Maximum Capacity parameter. To reduce simulation time, particularly in the peak load case, Maximum Capacity was set to limit hosting capacity just above the maximum possible capacity when reverse power flow would occur which is the combined load of the feeders attached to the bus. To be consistent for this study, all peak load analyses were run up to 25MW and all minimum load analyses were run up to 10MW for all feeders. ICA has the capability to simulate both peak and minimum loading conditions together as one simulation and only report the maximum hosting capacity between the two loading conditions. To better understand what the limiting factors were for each feeder, it was decided that for this study, the peak and minimum loading would be simulated separately. Fault contribution (the percentage of the DER's rated current) was set to a conservative estimate of 120% to match typical industry standard inverters of grid connected PV. All other parameters were set to typical values that PGE prefers.

	Parameter Used
Maximum Capacity	25MW for Peak Load, 10MW for Minimum Load
Power Factor of DER	0.95
Peak Load Factor	100%
Min Load Factor	Min Load/Peak Load *100%
Generation Tolerance	1kW
DER Fault Contribution (% of DER rated current)	120%

Table 1: Study Parameters

	Constraints Used
Integration Location	All 3ph, 2ph, and 1ph Sections
Thermal Loading	Thermal Rating of Each Device
Voltage Limits	0.95pu - 1.05pu (ANSI Standard)
Voltage Variation (Flicker)	1.5%
Reverse Power Flow	0% at Two-Winding XFMR
Protection Reduction of Reach	All Protective Devices at 0% Pickup Security Factor
Sympathetic Tripping	All Protective Devices at 0% Pickup Security Factor

Table 2: Study Constraints

INITIAL RESULTS AND ASSUMPTION CHANGES

The substation transformers, each distribution bus, and their associated feeders were initially simulated together, which posed a couple challenges for load flow results such as voltage limits and voltage flicker but especially with computational time. Ideally all the feeders should be included during the ICA analysis due to the effects the LTC and each feeder have on each other during load flow; however, it was discovered the simulation run time for all seven feeders analyzed concurrently exceeded 100 hours making it impractical to re-run the entire study. It was decided that each substation transformer would be simulated separately with its respective feeders to incorporate the effect of the LTC. For one of the transformers (T1), simulation run time for each of its feeders (Feeder 5, 6 and 7) exceeded 22 hours making it impractical to run all three of these feeders in a single simulation. For this transformer, the feeders were run individually to allow for practical simulation run times. Table 3 shows the transformer and its respective feeders that were included for each simulation. Table 4 shows each feeder analysis group simulation run time with the number of nodes per feeder analyzed during the simulation.

FEEDER ANALYSIS GROUPS			
FEEDER	TRANSFORMER	ANALYZED WITH OTHER FEEDERS ON SAME TRANSFORMER?	ANALYSIS GROUP
1	T3	Yes	1
2	T3	Yes	1
3	T2	Yes	2
4	T2	Yes	2
5	T1	No	3
6	T1	No	4
7	T1	No	5

Table 3: Feeder Analysis Groups

Feeder	Simulation Run Time[1]	Number of Nodes
1	24 hours	4306
2		800
3	15 hour	250
4		5776
5	22 hours	4593
6	32 hours	7104
7	26 hours	6165

Table 4: Feeder Simulation Run Time and Node Count

Table 4 Note :

1. Simulation Run Time is the approximate total time the simulation ran for each analysis group when using the using the applied parameters and constraints in Table 1 and 2 with CYME Version 8.0 Rev 4.

Another attempt at improving the simulation run time and efficiency of the study was changing from a laptop to a dedicated desktop with advanced computer specifications. It was found that improving the computer speeds and capabilities did not reduce simulation time but allowed for ICA to process multiple hosting capacity simulations simultaneously. This made it possible for multiple feeders to be simulated concurrently which in effect decreased the overall study time. Table 5 shows a comparison of computer specifications changed.

	Laptop	Desktop Computer
Processor	Intel® Core™ i5-6300U CPU @ 2.40 GHz	Dual Intel® E5-2650 @ 2.6GHz
RAM	12.0 GB	32.0 GB
# of Cores	4 Cores	32 Cores

Table 5: Computer Specifications

INTEGRATION CAPACITY RESULTS

Summary Table								
	Loading Conditions				Peak Load		Minimum Load	
Feeder[1]	Peak Load (MW)	Peak Load (MVAR)	Minimum Load (MW)	Minimum Load (MVAR)	Maximum Hosting Capacity[2] (KW)	Most Limiting Factor[3]	Maximum Hosting Capacity[2] (KW)	Most Limiting Factor[3]
1	11.62	3.19	3.06	0.16	1,220	Voltage Limits	4,489	Voltage Flicker
2	8.72	3.84	2.46	0.94	1,220	Voltage Limits	4,489	Voltage Flicker
3	7.51	3.00	1.24	0.29	15,443	Sympathetic Tripping	4,927	Sympathetic Tripping
4	8.79	1.77	4.49	1.45	15,443	Voltage Limits	4,927	Voltage Flicker
5	4.81	0.74	0.33	0.11	154	Voltage Limits	81	Voltage Limits
6	11.36	2.50	3.27	1.01	3,943	Voltage Limits	2,187	Voltage Limits
7	9.45	1.47	1.91	0.23	2,730	Voltage Limits	995	Voltage Limits

Table 6: Summary Results

Table 6 Notes:

1. Feeders 1 and 2 were connected to the same bus and simulated together. Feeders 3 and 4 were connected to the same bus and simulated together. Feeders 5, 6, and 7 are on the same bus but were simulated independently.
2. Maximum hosting capacity values for Feeders 1, 2, 3, and 4 represent the total capacity for all parallel feeders connected together on the same bus. Feeders 5, 6, and 7 maximum hosting capacity values represent maximum individual feeder capacity but are reduced due to existing voltage violations.
3. Most Limiting Factor corresponds to the parameter that limited the maximum hosting capacity at the most number of nodes for each feeder and loading case.

The summary results, shown in Table 6, displays each feeder's maximum hosting capacity in kW, Most Limiting Factor, and loading conditions in MW during peak and minimum load. As expected, there were different hosting capacities for each feeder due to different feeder topologies, but in all cases, the hosting capacity decreases the further downstream from the substation. As the distance from the substation increased, voltage limits and voltage flicker become the most limiting factors for almost all feeders. See Figure 1 and 2 for the Feeder 4 Hosting Capacity vs Distance from Substation plot and a hosting capacity one-line heat map for an example of this.

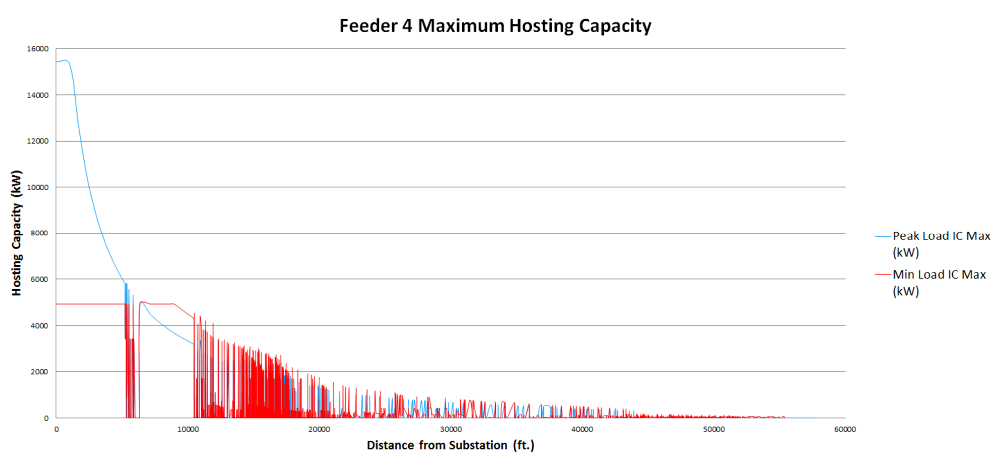

Figure 1: Feeder 4 Hosting Capacity vs Distance from Substation Plot

Figure 2: Feeder 4 Maximum Hosting Capacity Heat Map One-line (Combined Peak and Minimum)

The maximum capacity of a feeder was typically at the substation exit for each analysis group due to the reverse power flow constraint which stops the study once reverse power flow was recorded at the LTC. This is seen in Feeders 1 through 4 but not seen in Feeders 5, 6, and 7. Feeders 1 and 2, during peak loading conditions, had an existing high voltage profile in some regions of both feeders which limited the hosting capacity due exceeding voltage limits rather than reverse power flow.

Feeders 5, 6, and 7 were most limited by voltage limit violations, which can be explained by the high voltage profile on some regions of the feeders and low voltages in other regions that were observed in the initial baseline load flow during both peak and minimum loading. Because these three feeders were analyzed independently, the effect that the adjacent feeders and LTC had on the voltage profile worsened the existing conditions which reduced the hosting capacity.

LESSONS LEARNED

This Hosting Capacity study allowed PGE to investigate CYME's ICA module and perform a trial run for potentially using the tool to analyze their entire distribution network. The major take away from using CYME's ICA iterative method to calculate hosting capacity is the amount of computational processing sometimes required results in long simulation run times for larger feeders and especially if multiple feeders are modeled on the same bus. Since this study, CYME has made improvements to the ICA methodology, added a new protection constraint, and added additional reporting features to better analyze limiting factors which may reduce simulation time. However, if entire system wide analysis efforts are performed using this iterative approach, utilities will have to consider ways to reduce computation time but still ensure reliable results. There are suggested recommendations that were discovered during this study that would improve the results and simulation time allowing for additional scenarios to be analyzed and better verification of results.

1. Reduce the model's complexity so that the number of nodes is reduced and in result the simulation time is reduced but this comes at the cost of losing accuracy. Two items which almost tripled the number of nodes in the model was the inclusion of customer secondary networks and the substation distribution bus and adjacent feeders in the analysis. Removing these from the analysis may result in quicker simulation run times; however, the difference in accuracy has not fully been investigated.

2. Ensure model accuracy by manually testing the model at specific locations prior to running the ICA module. This can reduce debugging time for system model errors that result in the ICA simulations providing skewed or all zero results. This issue can become very time consuming and lead to significant back work in the end when debugging if there are existing violations or model databases and networks are not accurate.

3. A dedicated desktop with advanced specifications was used to in attempt to reduce simulation time; however, it was found that this did not decrease the simulation run time. Using a dedicated desktop with greater processing power and multiple CYME programs running simultaneously allows for more ICA simulations and quicker verification of results. Running the computationally intensive ICA module for long hours created issues with laptops or non-advanced computers causing them to freeze all simulations and lose all computed results. This can become an obstacle and delay results; therefore, it is recommended to use a dedicated desktop or server with advanced specifications to avoid these issues.

CONCLUSION

As more entities continue to install more DER and modernize the grid, optimizing hosting capacity calculation methodologies and improving integration of DER's into planning will become vital to ensuring utilities, regulators, and customers can make more intelligent, efficient and cost-effective solutions. CYME's ICA module provides node specific hosting capacity with a high level of accuracy and detail, but this high level of detail requires longer simulation times. ICA has the capability to adjust the parameters and constraints to define the level of detail and accuracy, which can be useful for reducing simulation time and obtaining verifiable results when system wide implementation begins. The recommendations made in this study are not the complete solutions to improving integration capacity analyses, but they are steps in the right direction in developing the integration capacity analysis process and increasing the electric grids capacity to integrate higher levels of DER penetration.

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