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Innovative Method to Determine Distributed Energy Resource Hosting Capacity

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SUMMARY

The amount of Distributed Energy Resource (DER) that any distribution network can accommodate, without adversely impacting system reliability or power quality, varies from distribution feeder to distribution feeder, within feeders in a network, and amongst locations on a feeder. Traditionally, the main factors driving the amount of DER that can be accommodated (hosting capacity), without necessitating changes in how the grid is designed or operated, are: 1) DER size/location, 2) DER technology/characteristics, and 3) distribution network design/characteristics. These factors are critically important in evaluating the impact of DER to the grid.

The Electric Power Research Institute (EPRI) developed the Distribution Resource Integration and Value Estimation (DRIVE) tool that enables distribution engineers with new planning methods that assess the Grid of the Future. The primary focus is to integrate and valuate existing and new distributed energy resources. Hosting capacity is the amount of DER that can be accommodated without adversely impacting power quality or reliability under current configurations and without requiring infrastructure upgrades. DRIVE has been developed in such a manner which allows it to be used with commercially-available distribution planning tools (e.g. Digsilent PowerFactory). DRIVE interfaces with the detailed network models that Eskom maintains, and calculates the hosting capacity of each network using new efficient methodologies and techniques. This allows the analysis to be conducted on the models that are created and maintained by Eskom. The case study presented concentrates on a section of Eskom Distribution network and looks at the variation in hosting capacity for different issues and feeders.

KEYWORDS

Distributed Energy Resources, DRIVE, Grid interconnection, System Planning

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1. INTRODUCTION

Technology improvement and falling costs have made the investment in technologies such as solar photovoltaics, electric vehicles, and storage an attractive option for customers, utilities, and third parties [1,2]. Adoption of these types of technologies involves the resources connecting directly to the distribution side of the power system. Distribution networks were originally designed with the sole objective of delivering electricity to the customer, distributed energy resources (DER) such as solar or storage were not considered. Therefore, there may be some adverse impacts to the distribution network if large penetration levels of DER begin to emerge. Hence, appropriate grid impact studies need to be conducted, using relevant tools, to ensure that the strategies are in place to mitigate any negative impacts.

A critical part of future distribution planning with DER is being able to determine the capability of the distribution network to accommodate or host DER. Hosting capacity is the amount of DER that can be accommodated without adversely impacting power quality or reliability under current configurations and without requiring infrastructure upgrades. One way to calculate the hosting capacity of a feeder is to perform numerous power flow simulations with varying sizes and locations of DER. However, this can become computationally rigorous, particularly if entire distribution networks/systems need to be analysed. The work in this paper describes an approach to determining hosting capacity using new efficient methodologies and techniques.

This paper will provide an overview of the methodology behind the new method, and present illustrative results from a case study using a section of the Eskom Distribution network.

2. METHODOLOGY

2.1. Background

The need for distribution planning tools that incorporate DER has been widely acknowledged by utilities as DER technologies have begun to emerge on distribution feeders. For a utility, the capability to quantify the amount of DER that their network can accommodate is a key element of these future planning tools. There are various methods available for doing such hosting capacity analysis. For a fast-simplified approach, interconnection screens can be utilised, however, the accuracy of results is often not adequate. A detailed power flow study can be performed and accuracy of results improved, however computation time can be slow, which is undesirable, particularly if an entire distribution network/system needs to be analysed. Additionally, the wide-range of scenarios that need to be considered (e.g. different DER locations, DER control, and distribution configurations) limits its applicability for performing distribution system-wide analysis. Therefore, a different method for analysing DER impacts on distribution networks, that captures the necessary grid impacts and can be applied more broadly across distribution networks, is needed.

EPRI, in developing a new method for performing hosting capacity, has implemented this approach in a new software module called DRIVE (Distribution Resource Integration and Value Estimation). This new hosting capacity method described in this paper, falls in between the detailed and screen approaches as shown in Figure 2-1. Computation time is far less than a detailed study, and as the method stems from previous detailed studies, accuracy of results is maintained.

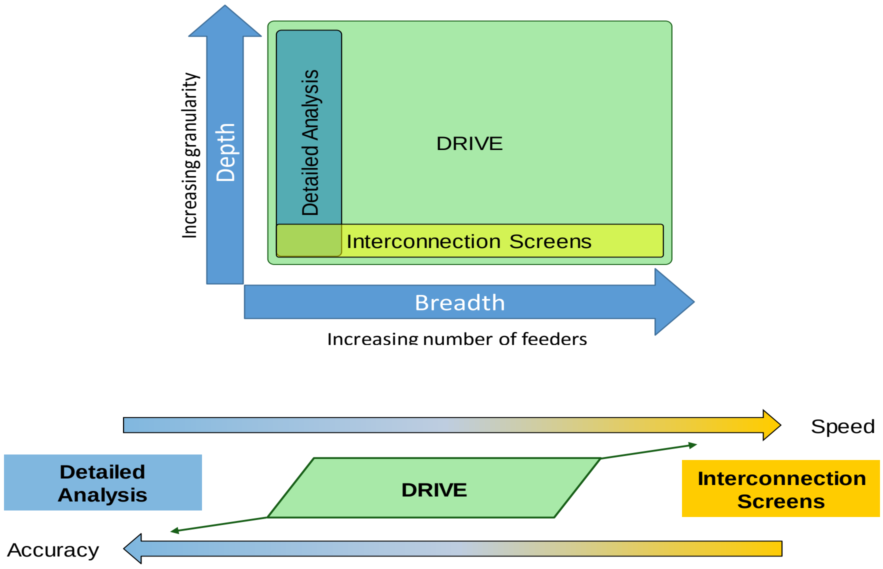


Figure 2-1 Speed vs accuracy of different hosting analysis approaches

The fundamental difference between DRIVE and Detailed Analysis is outlined in the basic flowchart shown in Figure 2-2. Detailed analyses must iterate through thousands of load flows of the model with specific DER scenarios to determine impact, while DRIVE utilizes very few load flows, extracts all pertinent information needed to calculate DER impact, and then examines DER scenarios to determine DER impact. The base load model is always the same in each analysis, so by extracting the characteristics of that model in DRIVE, the main variable (DER scenario) can be applied externally more efficiently [3].

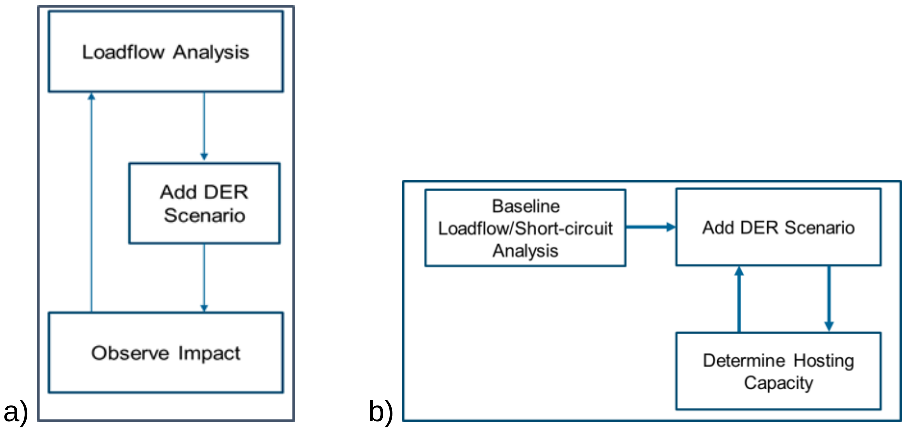


Figure 2-2. Flowchart for a) Detailed Analysis b) DRIVE

2.2. DRIVE Methodology

From previous detailed hosting capacity analysis studies [4,5] it was observed that the hosting capacity of distribution feeders for DER is primarily dependent on: the size of the DER, the location of the DER, and the characteristics of the feeder. These were therefore considered key aspects when developing the method. As a result, the DRIVE methodology is grounded in the distribution feeder models and power flow simulation to ensure the characteristics of the feeder are being fully captured [6,7]. A number of power flow and fault study simulations are performed at the beginning of the analysis to determine the conditions of the feeder without any DER. Once this initial data is captured, no further power flow studies are required. In order to determine hosting capacity, DER is layered on top of the base power flow results and calculations are used to figure out how the additional DER will modify the underlying voltages and currents. The DER is then scaled up until one of the feeder thresholds is exceeded.

The DER assessments are then performed by applying various DER “scenarios” based on current injection. These scenarios consider centralized (single-site) and distributed (multiple-site) DER locations. Thousands of scenarios are examined when considering all potential locations, or “nodes”, on the distribution feeder. A simplistic illustration of a small subset of scenarios is shown in Figure 2-3. These scenarios make up the basis of the DER impact analysis. Each scenario results in a node-specific hosting capacity for DER at a specific location. 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 multiple hosting capacities at each node – two based on Distributed DER and another based on Centralized DER. The two distributed DER scenarios encompass Distributed Large (utility class) DER and Distributed Small (customer class) DER. The number of hosting capacity values then scales linearly with the number of distribution impacts (evaluation criteria) considered [3].

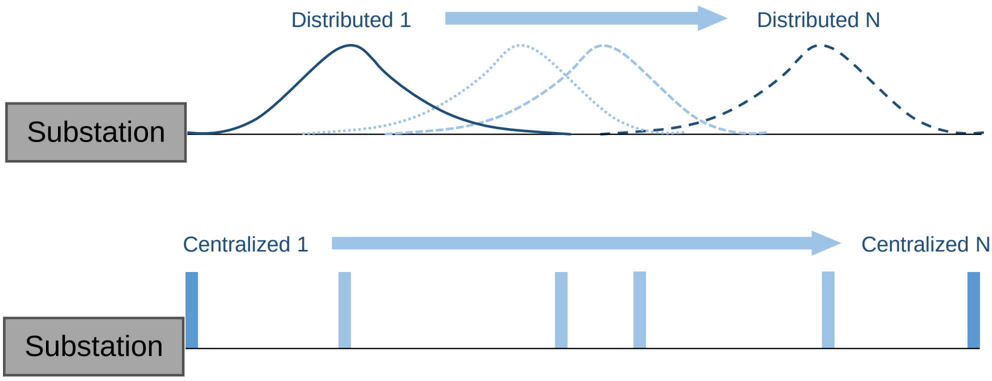


Figure 2-3 Deployments of DER analysed using DRIVE’s method for hosting capacity

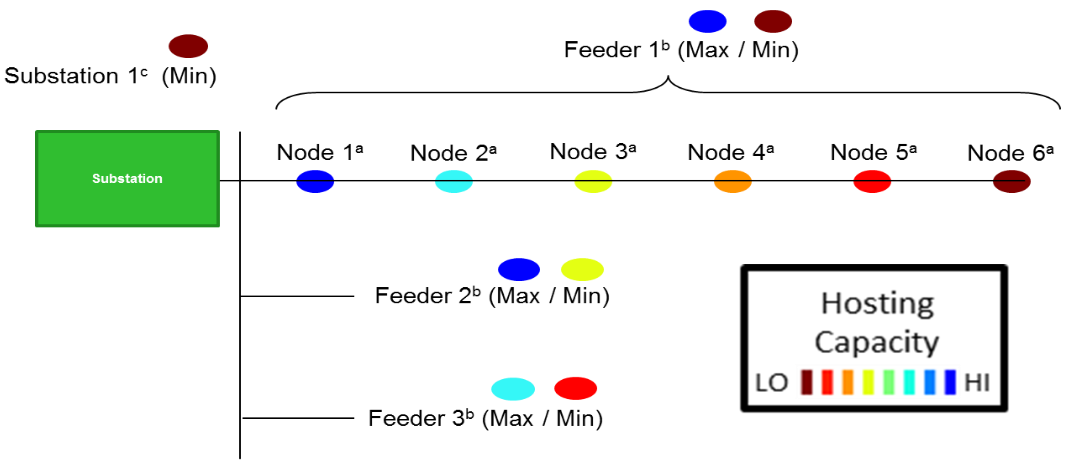
The network/feeder issues considered are shown in Table 2-1. These are broken down into three categories: voltage issues, thermal issues, and protection issues. Primary overvoltage and undervoltage are determined by the voltage limits of the feeder, usually dictated by the local distribution grid code. Voltage deviations cover the range in possibilities that overvoltage or undervoltage could occur from sudden changes in DER output. Voltage deviations at regulation nodes are important if reduced asset life due to potential increased operations is a concern. Thermal issues refer to the rating of elements such as lines and transformers. The addition of DER may cause excess current to flow through these elements, which can be damaging over prolonged periods of time. Protection issues occur due to increased fault current from DER. Increased fault currents impact the coordination between fuses and other automatic protection, the visibility for the breaker to determine remote feeder faults, as well as sympathetic breaker operation. Unintentional islanding and reverse power flow are also undesirable so it is important to monitor the bi-directional power flows.

Table 2-1 Network/Feeder issues considered

Category	Criteria	Basis	Hosting Capacity Threshold
Voltage	Primary Over-Voltage	Feeder voltage limit at any node	1.05 Vpu voltage magnitude
	Primary Under-Voltage	Feeder voltage limit	0.95 Vpu voltage magnitude
	Primary Voltage Deviation	Change in voltage from no DER to full DER at any node	3% voltage change
	Regulator Voltage Deviation	Change in voltage from no DER to full DER at a regulated node	50% of bandwidth at regulators
Loading	Thermal for Charging (Demand)	Remaining capacity at peak loading for any element	100% normal rating
	Thermal for Discharging (Generation)	Rating plus minimum loading for any element	100% normal rating
Protection*	Additional Element Fault Current	Deviation in feeder fault currents at any location	10% fault current increase
	Sympathetic Breaker Relay Tripping	Breaker relay zero sequence current	150A ground current at the feeder head relay
	Breaker Relay Reduction of Reach	Deviation in breaker fault current	10% current decrease
	Reverse Power Flow	Element minimum loading	100% minimum loading
	Unintentional Islanding	Element minimum loading	100% minimum loading

The methodology described discusses how to find the hosting capacity for each node on a feeder. However, oftentimes it is necessary to determine what the overall feeder or substation hosting capacity is. An example of how these are determined is shown in Figure 2-4. 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 colours indicate the resulting hosting capacity. The feeder hosting capacity is then the range in node hosting capacity on the entire feeder. The feeder's Max/Min range is based on DER at the most/least optimal locations, respectively. It is important to note that the feeder hosting capacity IS NOT the summation of individual node hosting capacities.

Each feeder can then be analysed independently to determine their node/feeder hosting capacities. Aggregating further to the substation, one could determine the substations ability to accommodate DER. The substation hosting capacity is a representation of the ability of its feeders to accommodate DER. At the substation, the "Min" hosting capacity is the minimum of all feeder minimums. The substation hosting capacity is not based on separate substation issues, although those issues will be included in subsequent releases of DRIVE [3].



[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.
[c] Substation Hosting Capacity represents the Minimum of the Feeder Hosting Capacities.

Figure 2-4 Node, feeder, and substation hosting capacity aggregation

The above example shows the hosting capacity for one issue, however, as shown in Table 2-1, there are many issues that are considered in the hosting analysis.

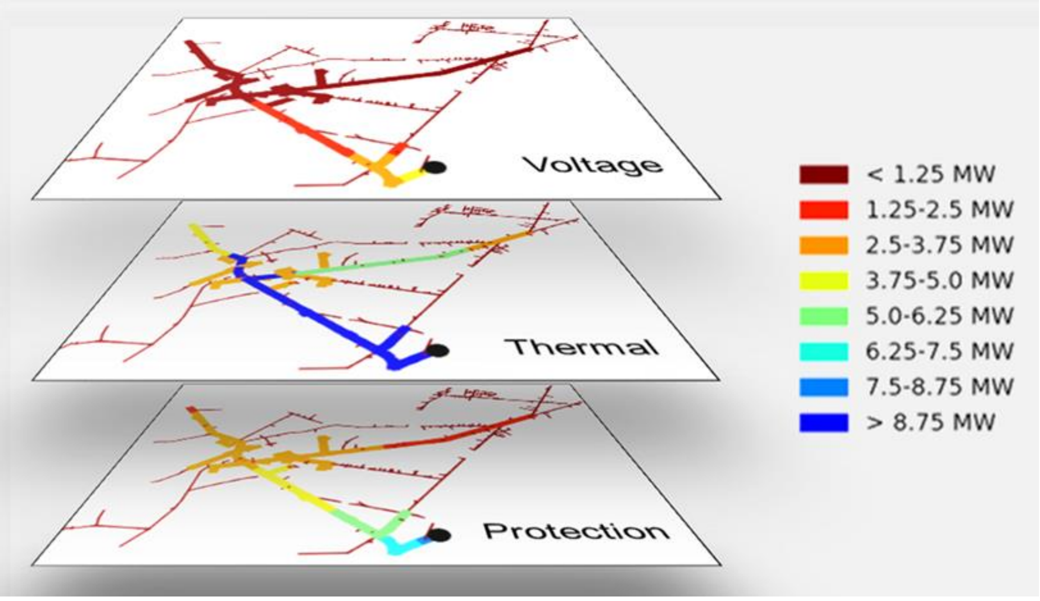


Figure 2-5 shows the how the hosting capacity of a feeder is determined when considering multiple issues. The three figures on the left depict a geographical representation of a feeder with the node level hosting capacities for voltage issues, thermal issues, and protection issues overlaid. The hosting capacity for each node is shown by the colour at that node. In order to determine the overall hosting capacity for the feeder, the minimum hosting capacity from the three issues for each node is extracted as the overall hosting capacity for that node. This is illustrated by the figure on the right. In this example, the voltage issues are the limiting factor for hosting capacity, therefore these values determine what the overall hosting capacity for the feeder will be.

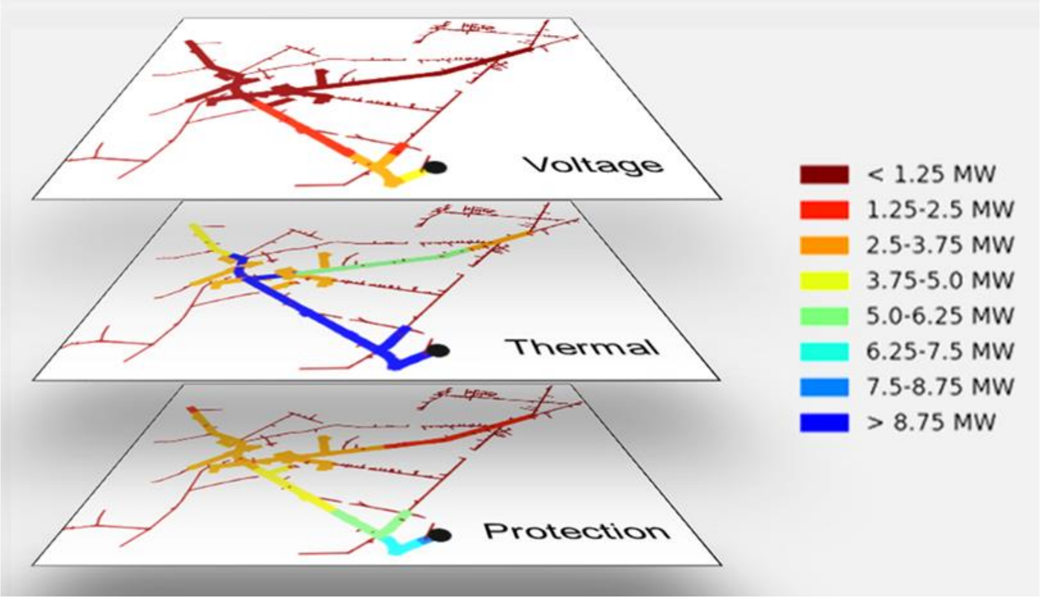


Figure 2-5 Node level hosting capacity for three different impacts to overall hosting capacity

As discussed previously, although node level hosting capacity is useful, it is important to capture feeder and substation levels too, and be able to visualise them as is done for the node-level shown in Figure 2-5. Figure 2-6 gives an example of how hosting capacities can be visualised at different levels. The node level hosting capacity is shown in the figure on the far right. It is shown the same way as in Figure 2-5 where each node has a hosting capacity which is represented by the colour at that node. The next level up is the feeder level hosting capacity, which is depicted in the middle figure. All feeders connected to the same substation are shown together. The colour of each feeder indicates the minimum hosting capacity of that feeder. The highest level of hosting capacity that can be visualised is the substation level, which is shown in the far-left figure. As with the feeder level, the colour assigned to each substation indicates the feeder with the lowest hosting capacity that is connected to that substation. The various visualisation levels can be valuable in different ways. For example, the node level can provide the degree of detail required for informing interconnection studies, while the substation level could be used on an entire distribution network in a planning capacity.

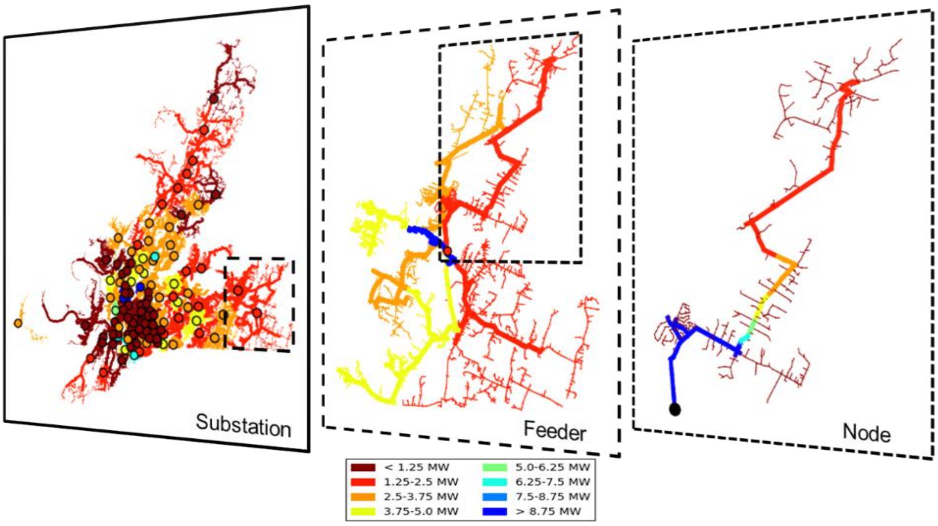


Figure 2-6 Node, feeder, and substation level hosting capacity

The DRIVE hosting capacity methodology and results have a number of potential applications in various areas [8] which are described in Table 2-2.

Table 2-2 Potential applications for DRIVE's hosting capacity method

System-Wide Distribution Planning	• Determine DER impacts and hosting capacity on a feeder-by-feeder basis across the entire distribution network • Calculate capacity for accommodating new loads • Evaluate impacts on grid reconfiguration (operational flexibility) • Evaluate impacts and solutions realized through new technologies such as smart inverters
DER Hosting Capacity	• Improve screening techniques that effectively account for the proposed DER and associated grid capacity at that location • Identify locations that can minimize the upgrades necessary to accommodate DER • Provide better visibility to the specific issues that arise, where, and how often they might occur throughout the distribution network • Improve visibility into feeder- and substation-level capacity for accommodating DER • Inform transmission studies
Economics	• Provide technical basis for cost benefit assessments – Integrated Grid • Provide starting point for analysis of Energy, Asset Deferral, Mitigation

3. EXAMPLE CASE STUDY AND RESULTS

To date, the DRIVE hosting capacity analysis has been successfully applied to numerous distribution networks and feeders globally [3, 9,10,11]. However, the case study discussed in this paper studies the application of hosting capacity method to a section of the Eskom Distribution network, as part of a recent joint project between the Electric Power Research Institute (EPRI) and Eskom Holdings SoC Limited [11]. The feeders have voltage levels ranging from 11kV and 22kV. The feeders vary in characteristics as they are a mixture of various load types and configurations in different Eskom Distribution supply areas.

Figure 3-1 shows the System View of Substation-Level Hosting Capacity for 70 feeders. The substation-level hosting capacities illustrated are based on the minimum hosting capacity of all feeders connected to the substation. There are 58 distinct substations (circles in plot) connecting to the 70 feeders. Many substations only serve one feeder in the subset of feeders analyzed, however, more feeders connect to those substations yet were not included in the subset of feeders analysed. The hosting capacity results shown in various colours for each circular dot in Figure 3-1 are based on the impact from Centralized Large DER. The substation total hosting capacity (i.e. 52.1 MW), is the sum of the minimum hosting capacity from each individual substation. Without the entire distribution network modeled, the value is incomplete since the value would change.

The embedded table shows the issues considered in the figure's visualization. The table indicates that the most common limiting factor of the feeders is Primary Voltage Deviation based on the 0.9 MW 'Mean' value. For most substation's, the protection issue shown is less of a concern.

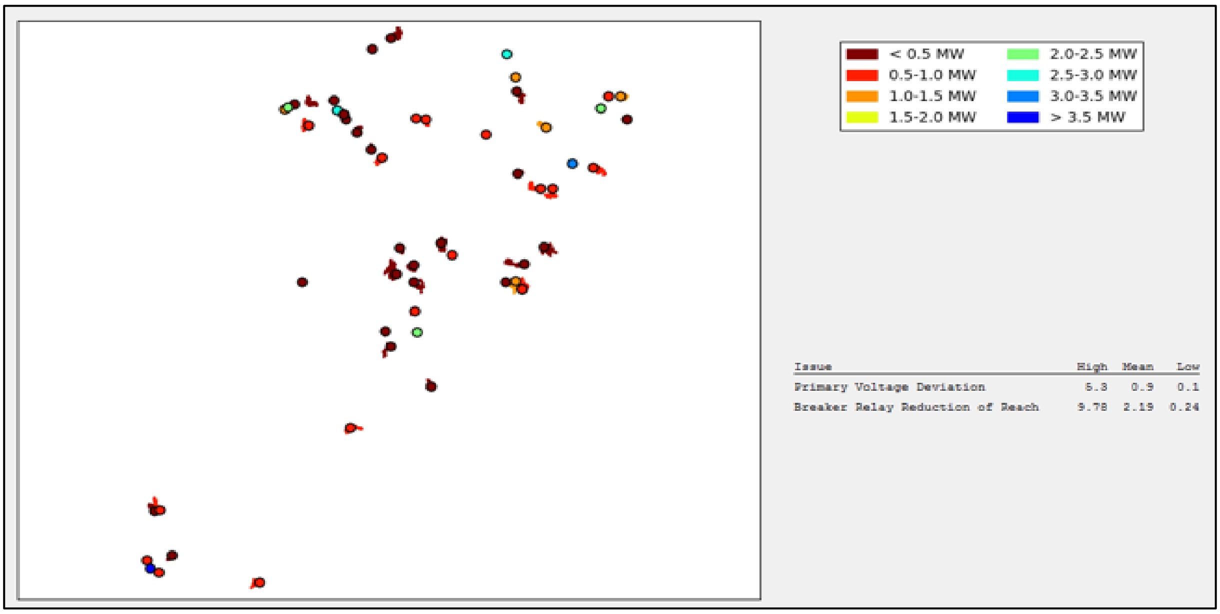


Figure 3-1. System View of Substation-Level Hosting Capacity

From the System View, the user can zoom into the Substation View as shown in Figure 3-2 for Substation ABC. In the Substation View, the feeder level results are shown for both feeders that the substation serves. One feeder (ABC-ALPHA) has a higher hosting capacity than the other (orange feeder). The second feeder has a low hosting capacity as indicated by the red color range. The lower hosting capacity feeder (ABC-BETA) sets the Substation-Level hosting capacity at 0.7 MW.

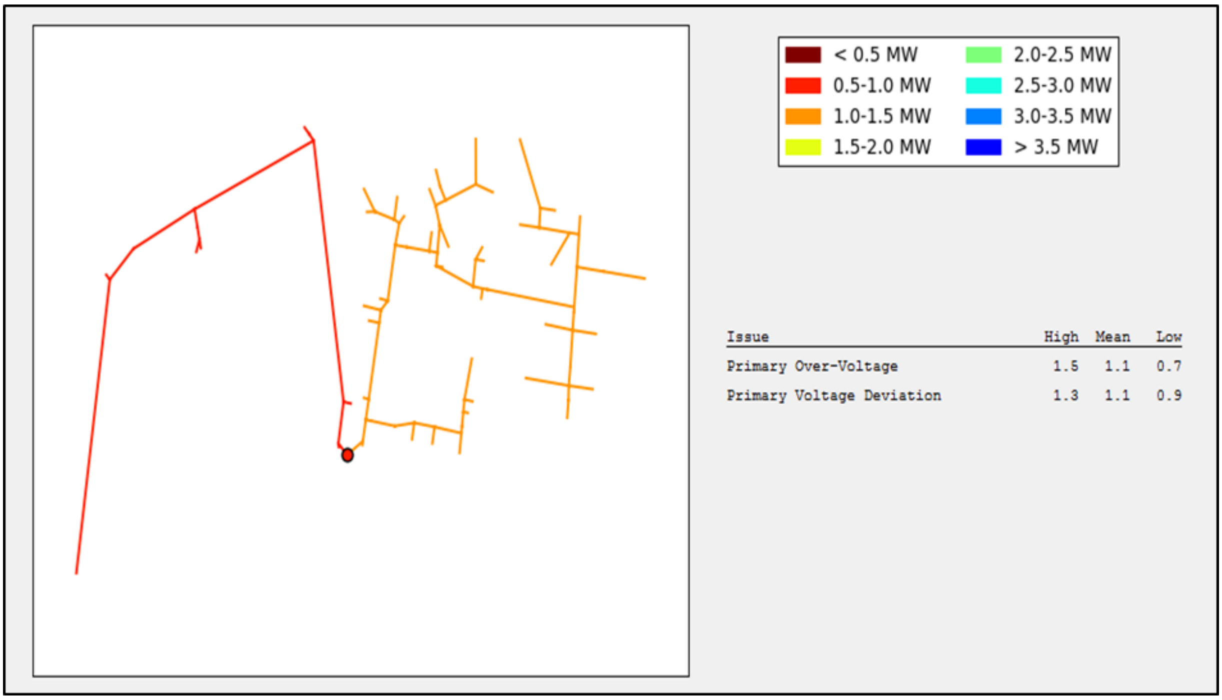


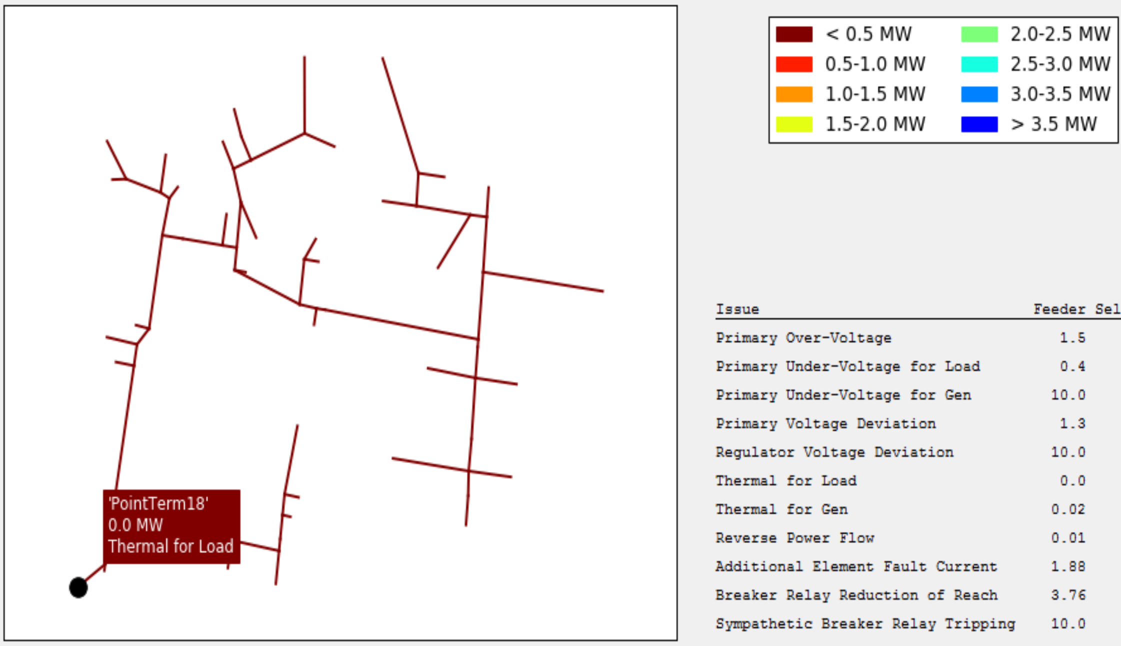
Figure 3-2. Substation View of Feeder-Level Hosting Capacity

From the Substation View, the user can zoom into the Feeder View as shown in Figure 3-3 for ABC-ALPHA. The node-level hosting capacity schematic indicates the minimum hosting capacity based on all issues selected at each individual node. The interactive plot would indicate and display the limiting issue/value at any particular node when the node is selected. The lowest hosting capacity is 1.3 MW but only applies to the remote ends of the feeder.

Figure 3-3. Feeder View of Node-Level Hosting Capacity

Adding all evaluation criteria as shown in Figure 3-4 indicates that there may be further limitations to hosting capacity if additional issues are applied. A specific location on the feeder has been chosen and the hosting capacity value at that location is shown. This location indicates that the limiting issue is at 0.0 MW due to thermal load charging. However, if the thermal load charging condition is not being considered as a limiting factor at that location, the embedded table can be used to determine the next limiting factor. Reverse power flow and unintentional islanding are the next limiting issue at 1.22 MW. After that, the next limiting factor at the selected location occurs at 3.1 MW due to generator discharging thermal condition.

In addition to these issues shown, there may also be general planning limits that cap the amount of DER that could be placed on a feeder. In the figure, EPRI analysed hosting capacity to 10 MW, but that amount of DER may exceed the planning limit, thus the maximum penetration level for the analysis could be reduced.



Issue	Feeder	Selected
Primary Over-Voltage	1.5	10.0
Primary Under-Voltage for Load	0.4	4.4
Primary Under-Voltage for Gen	10.0	10.0
Primary Voltage Deviation	1.3	10.0
Regulator Voltage Deviation	10.0	10.0
Thermal for Load	0.0	0.0
Thermal for Gen	0.02	3.1
Reverse Power Flow	0.01	1.22
Additional Element Fault Current	1.88	10.0
Breaker Relay Reduction of Reach	3.76	3.76
Sympathetic Breaker Relay Tripping	10.0	10.0
Unintentional Islanding	0.01	1.22

Figure 3-4. Feeder View of Node-Level Hosting Capacity Adding All Evaluation Criteria

The range in hosting capacity values for each individual issue on the ABC-ALPHA feeder are shown in Figure 3-5. The figure illustrates that adverse impact can begin for thermal load charging issues at 0.0 MW, but the location of DER may be more optimal and whether there is adverse impact really depends upon the DER location. Each issue has its own range in hosting capacity. Sympathetic breaker relay tripping is always below threshold for Large DER because the assumed interconnect transformer does not contribute to ground source currents. Regulator Voltage Deviation also shows no adverse impact because there are no regulators modeled for the feeder.

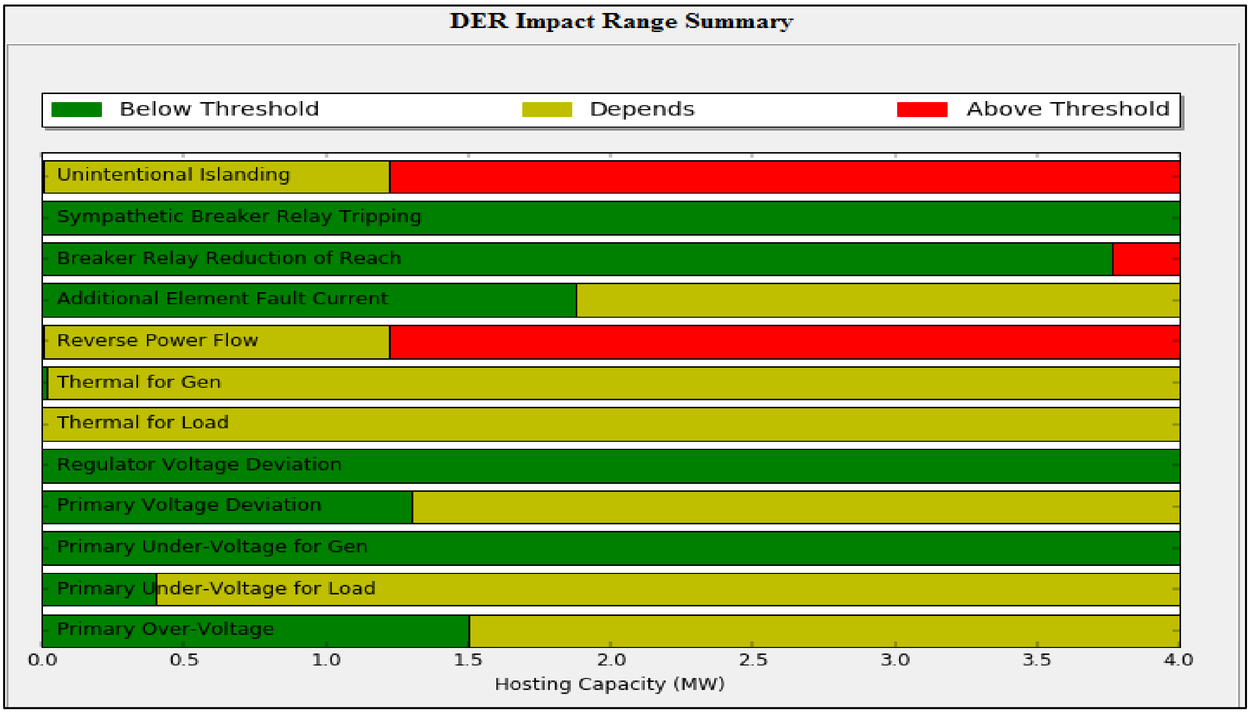


Figure 3-5. Range in Node-Level Hosting on ABC-ALPHA for All Evaluation Criteria

As more and more DER connects to the low voltage (LV) system, e.g. rooftop PV, heat pumps, and electric vehicles, it will become increasingly important to investigate LV hosting capacity. This may present some challenges, as models of the LV system will be required which at present are generally not available. Modelling the impacts at LV is even more important from a South African perspective, where the LV network can be rather wide. Although this may be a challenge, it is something that will be important to consider in future studies [10].

4. CONCLUSIONS

This paper has presented the background and the innovative methodology to determine distributed energy resources hosting capacity developed by EPRI and contained within the Distribution Resource Integration and Value Estimation (DRIVE) tool. DRIVE provides the industry a way to perform the hosting capacity analysis on a system-wide basis more quickly without compromising accuracy. An example of the Node-level hosting capacity for a sample Eskom Distribution network was presented. Results of the composite hosting capacity based on multiple criteria including primary node overvoltage, primary voltage deviation, thermal issues due to generation, reduced breaker relay sensitivity, etc.; were demonstrated. The results indicated that every feeder is designed a different way and effectively has a unique hosting capacity. There are no two feeders that are identical and thus no two feeders share the same hosting capacity. Hosting capacity is also very dependent on the criteria selected to include in the analysis and what thresholds are applied to define when adverse impact occurs. In addition to the feeders, criteria, and thresholds, the DER type and distribution also play a key role in hosting capacity calculations. Hosting capacity is not a static value for a feeder or location on a feeder. The value will change as the distribution network changes. Hosting capacity can also change with Grid and/or Customer impact mitigation. The most appropriate impact mitigation will depend on the adverse impacts that occur.

The key objective of using the DRIVE tool is to provide Eskom Distribution planners information to inform DER interconnection requests, support DER developer's understanding of more favourable locations for interconnection, and enhance system planning using efficient and reliable methods and techniques.

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