This webcast will be recorded

Grid Hosting Capacity

Fundamentals and Applications

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EPRI
Distribution Operations and Planning

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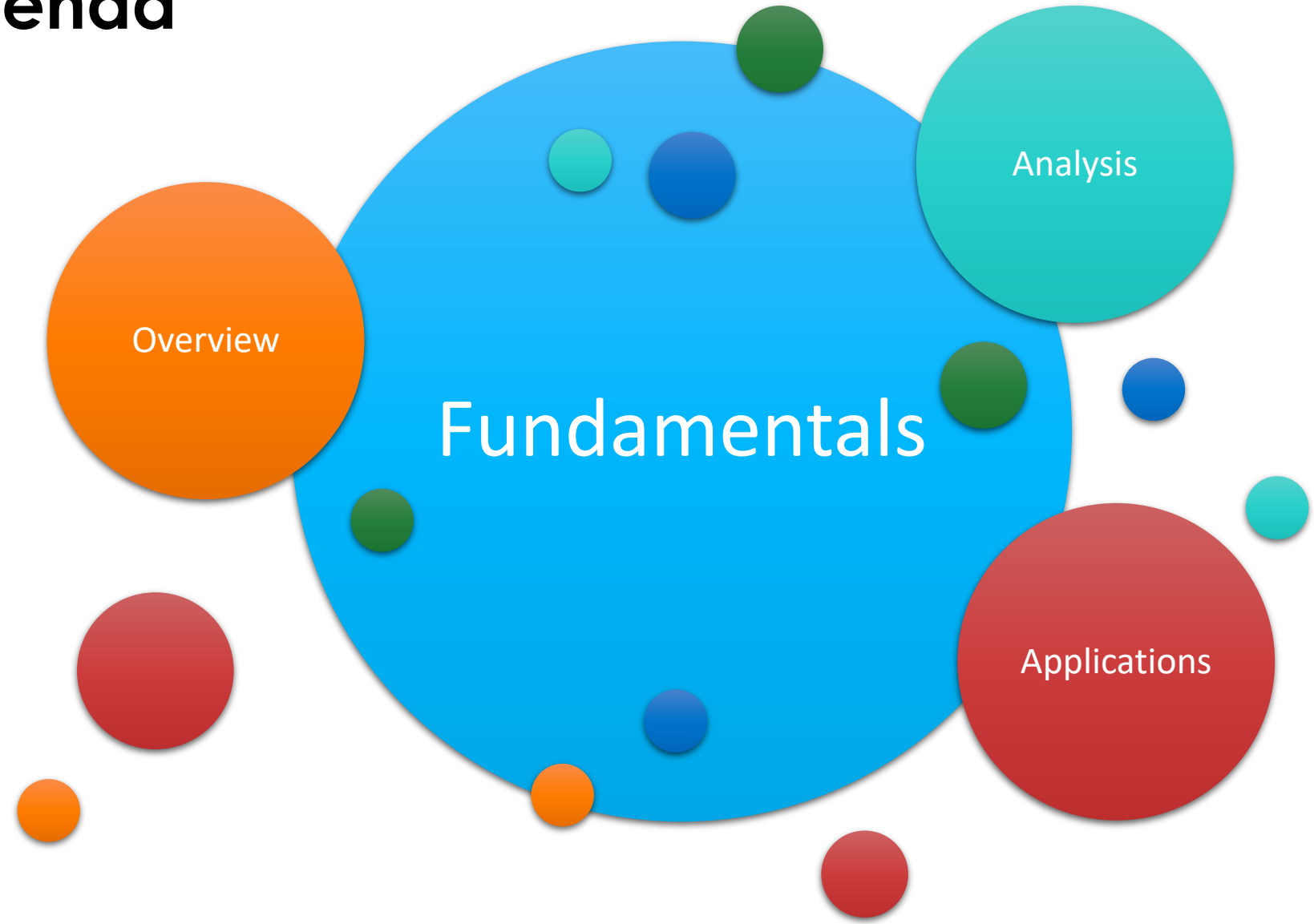
Agenda



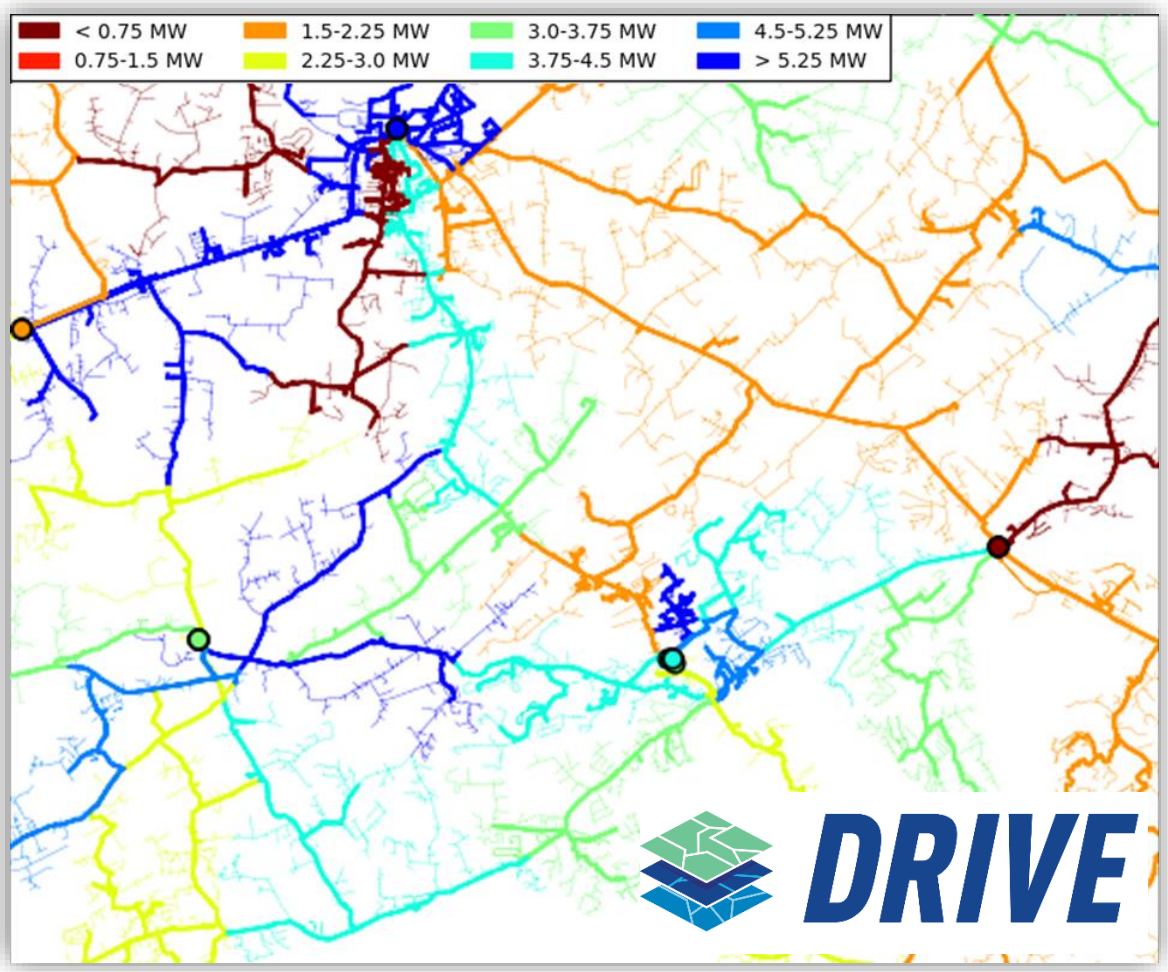
Key objectives:

- Understanding of hosting capacity
- Awareness to options within the analysis
- Considerations for breadth of applications

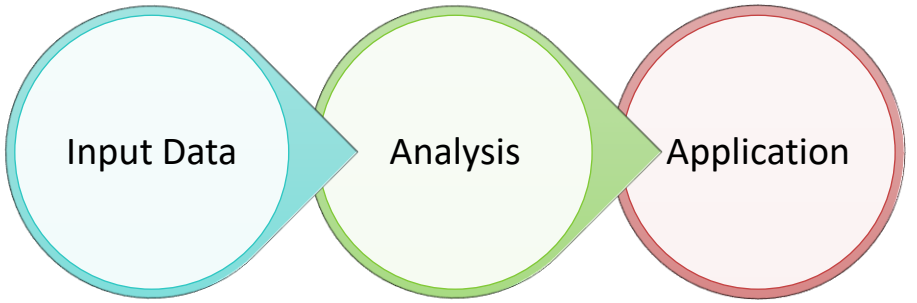
OpenDSS files and Python scripts provided in the shared folder:

Overview

Hosting Capacity Analysis



Hosting capacity results estimate the amount of future load or generation that can be **accommodated** without adversely impacting power quality or reliability under current configurations and without requiring infrastructure upgrades.

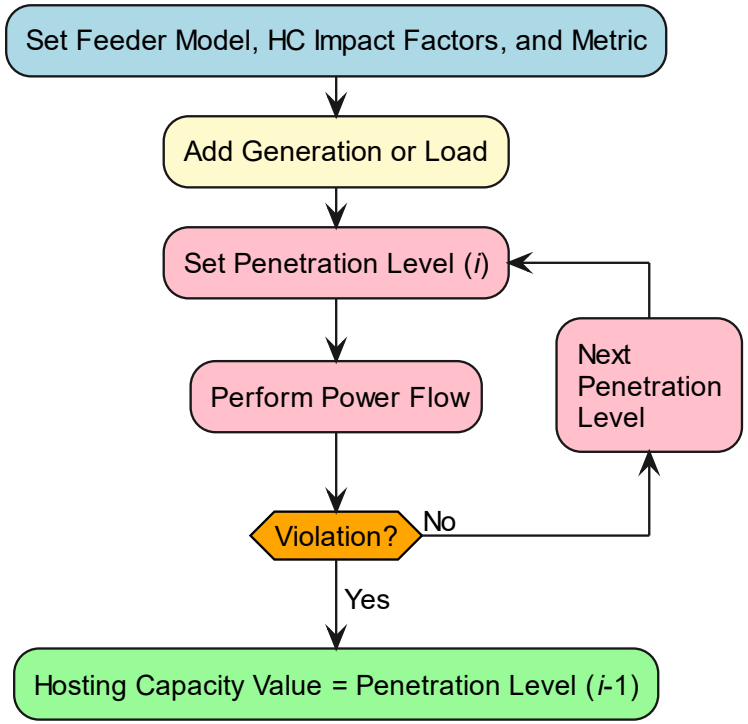


The Hosting Capacity Process. EPRI, Palo Alto, CA: 2020. 3002019750.

Hosting Capacity: High Level Flowchart

- **Set Feeder Model, HC Impact Factors, and Metric ***
  - Define the feeder conditions (load demand, existing DER…)
  - Establishes how to consider some additional impact factors.
  - Set the metric/criteria (such as overvoltage, undervoltage, thermal loading, etc...) to be evaluated.
- **Add Generation or Load**
  - Add new/future load** or generation
- **Set Penetration Level *(i)***
  - Increase penetration according to iteration *i*.
- **Perform Power Flow**
  - Solve the power flow with new/future DER to see grid impacts
- **Violation?**
  - Check if the power flow results violate pre-defined metric/criteria thresholds.

- Process finishes when there is a violation the ➔ hosting capacity value for the selected criteria is the penetration level of the previous iteration.

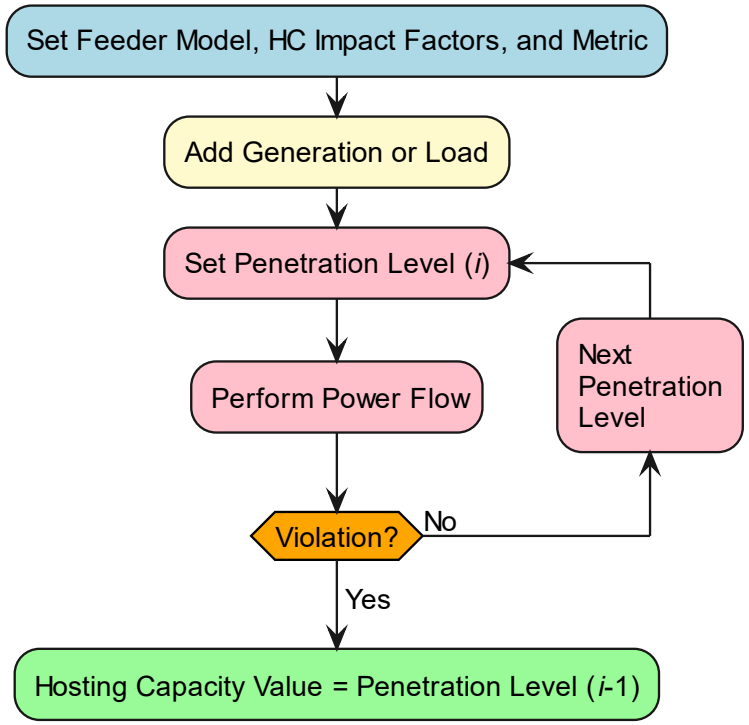


** Depending on how this step is defined, the hosting capacity value might change.*

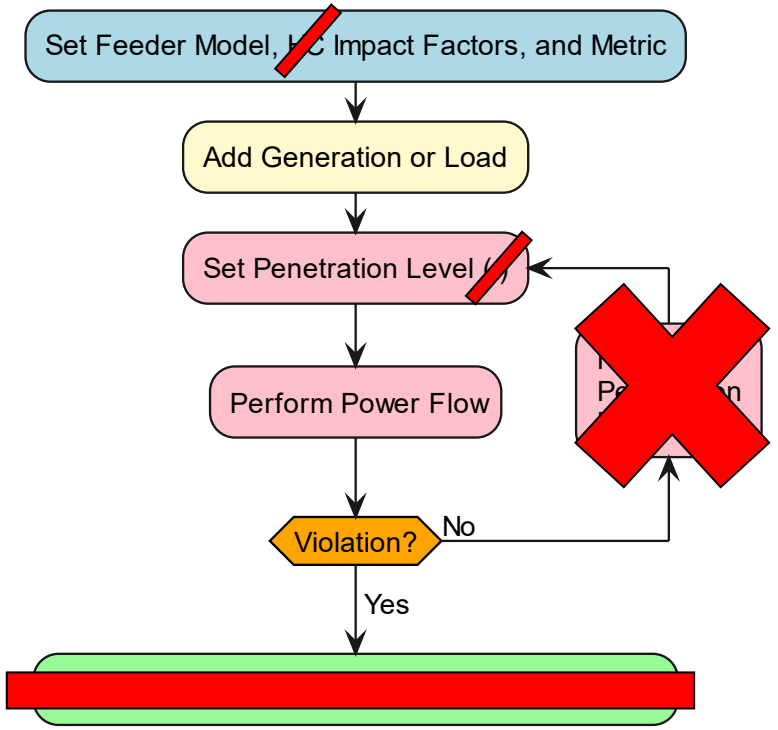
*** Note that the penetration and the violations considered could be for future load or generation. Hosting capacity assessments are not limited to accommodation of future generation as commonly thought.*

Hosting Capacity Analysis vs System Impact Study

Hosting Capacity Analysis

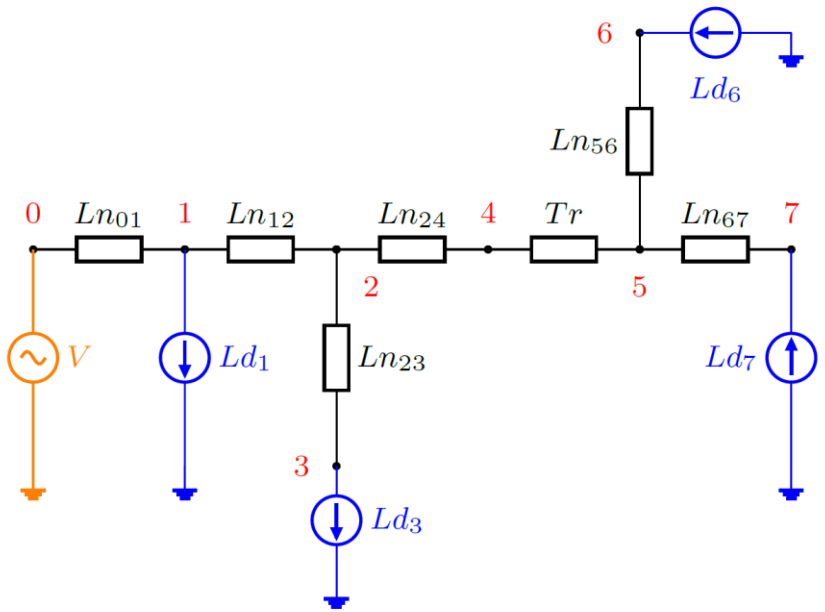


System Impact Study



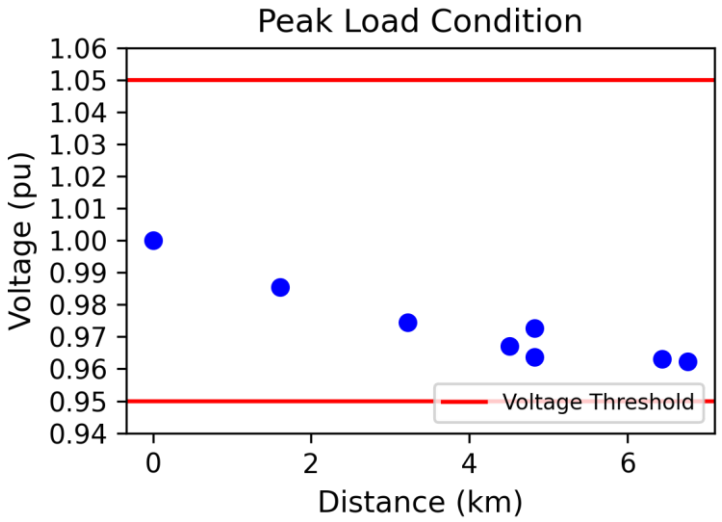
Simple Test Feeder Example

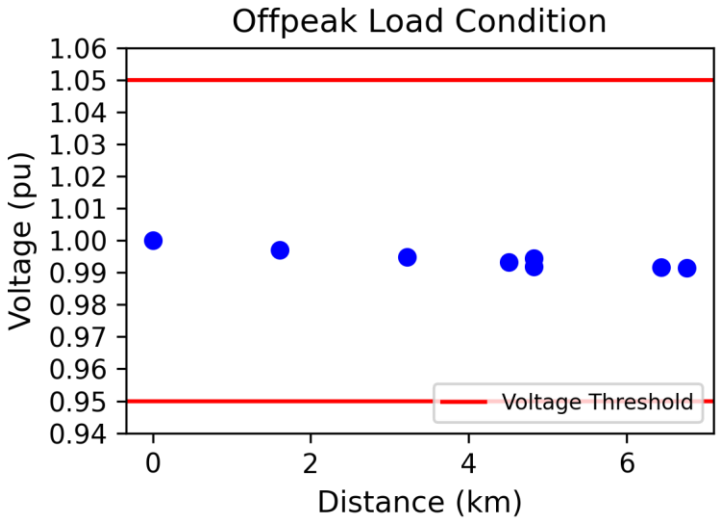
The simple test feeder is used throughout this section.



Feeder Characteristics:

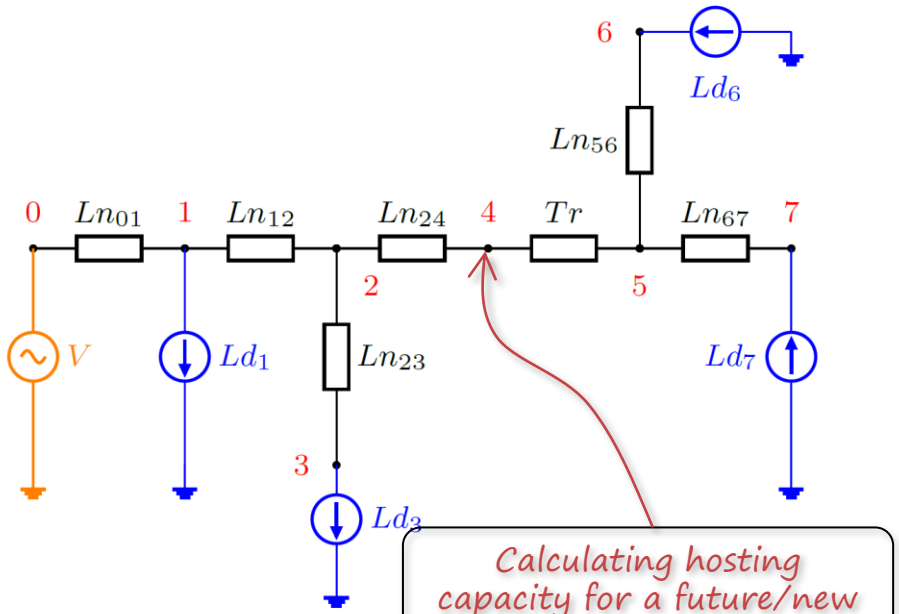
- 8 buses
- 6 lines
- 1 transformer
- 4 loads
  - 1.25 MW Peak load condition
  - 0.25 MW Offpeak load condition
- File: feeders\8bus\Master.dss

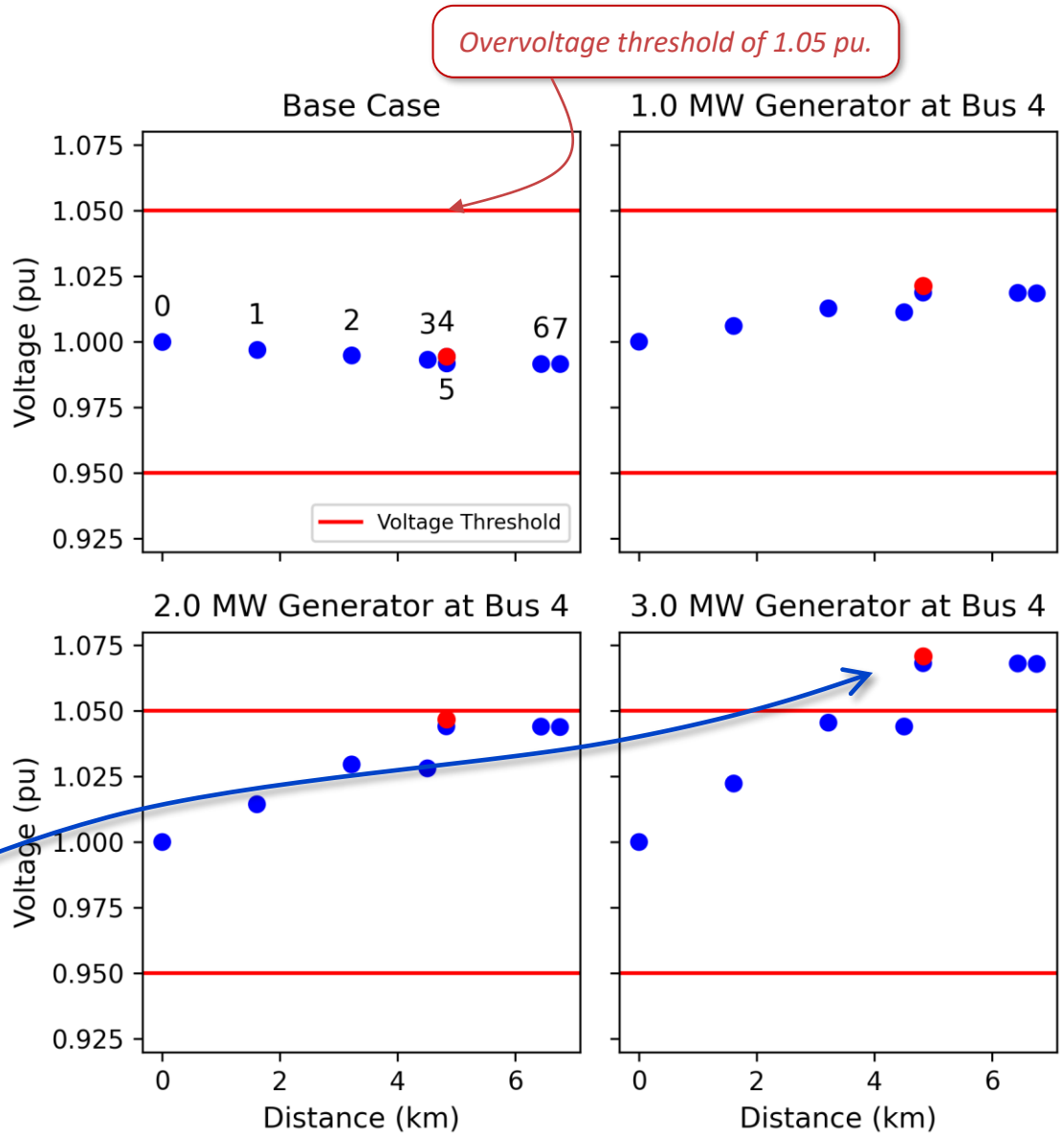




Generator Impact on Feeder Voltage Profile

Increment the generator penetration level (1 MW steps) and observe the impact on the voltage profile.



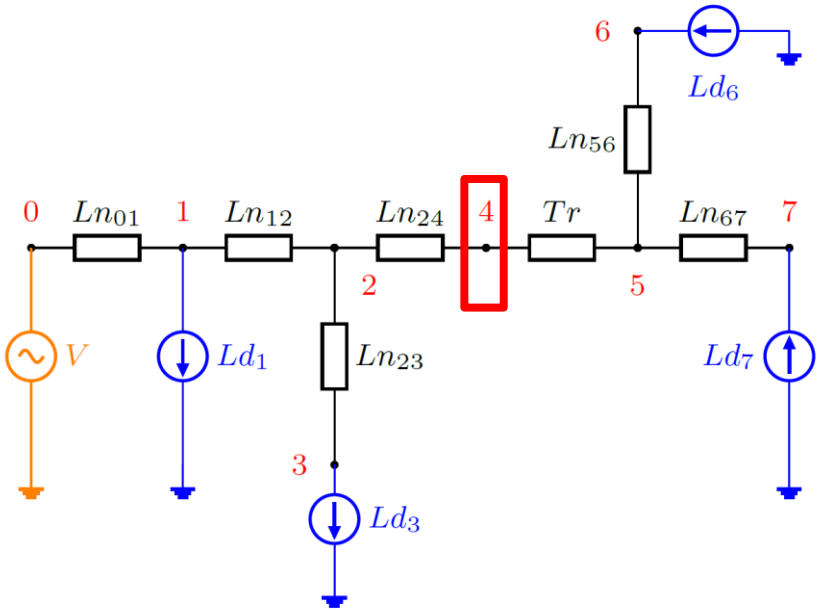


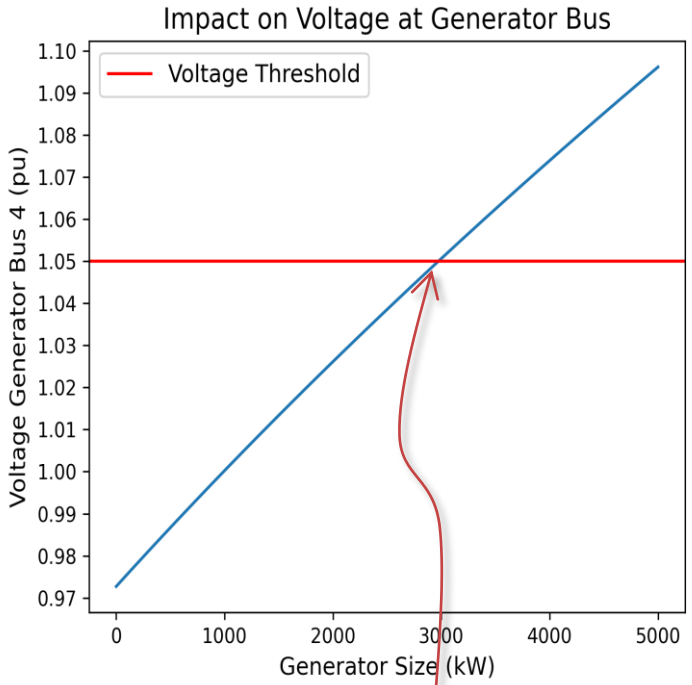
Takeaways:

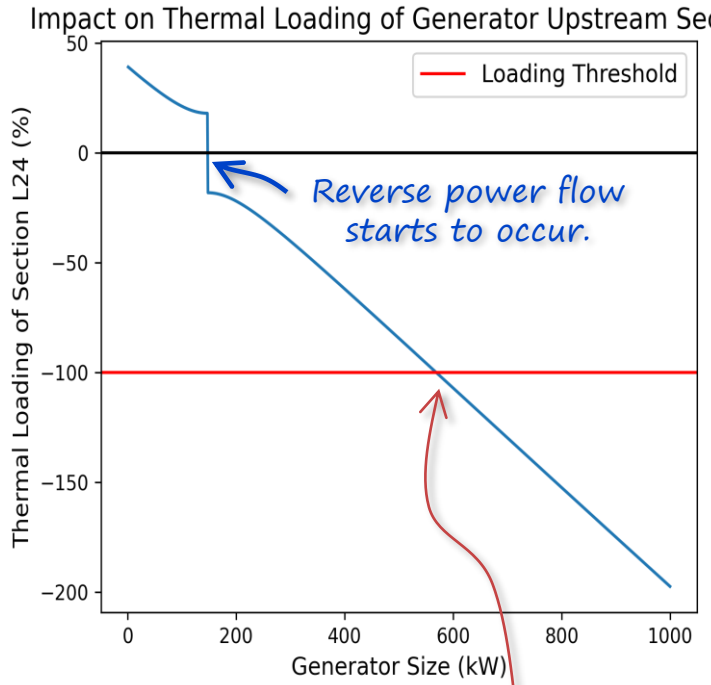
1. The voltage increases gradually with penetration increments.
2. There is a penetration level at which the overvoltage threshold starts to be violated.

Generator Induced Voltage and Thermal Impacts

Check the bus and section to which the generator is connected.







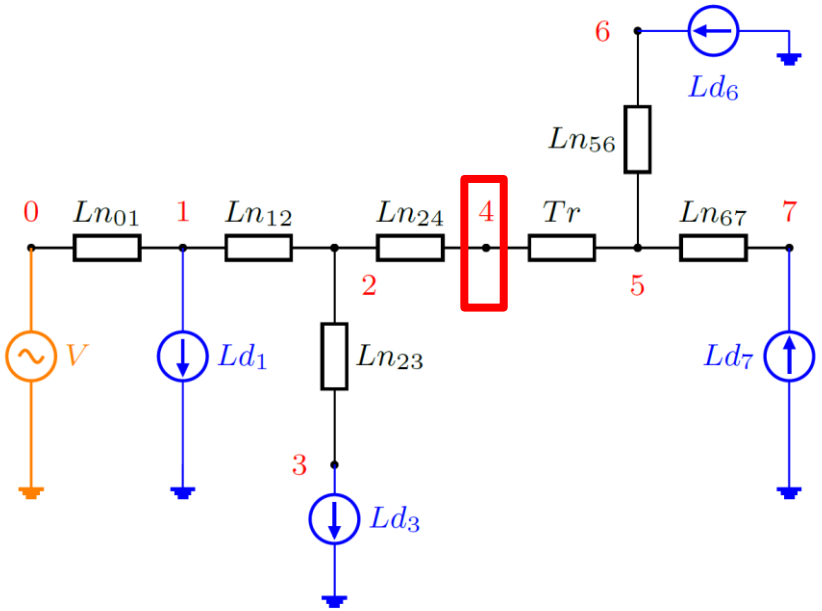
The penetration (2.97 MW) level at which the voltage limit of bus 4 begins to be violated.

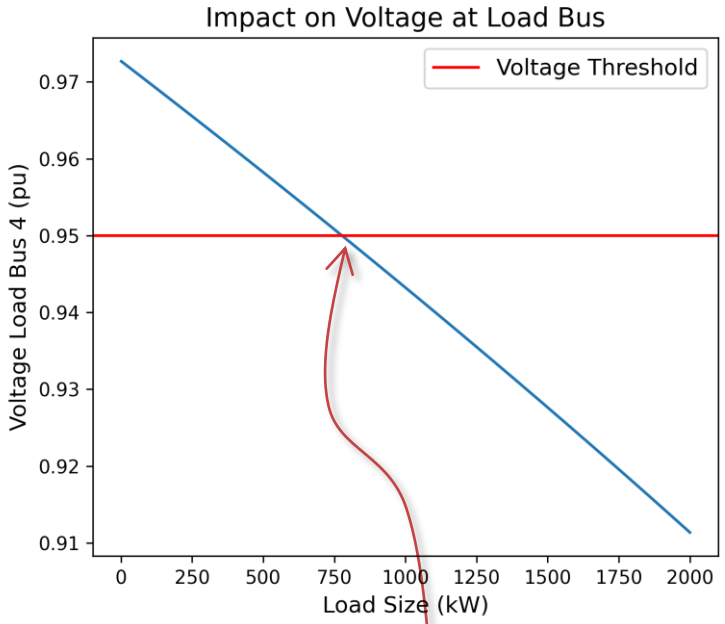
The penetration (0.57 MW) level at which the thermal loading limit of L24 section begins to be violated.

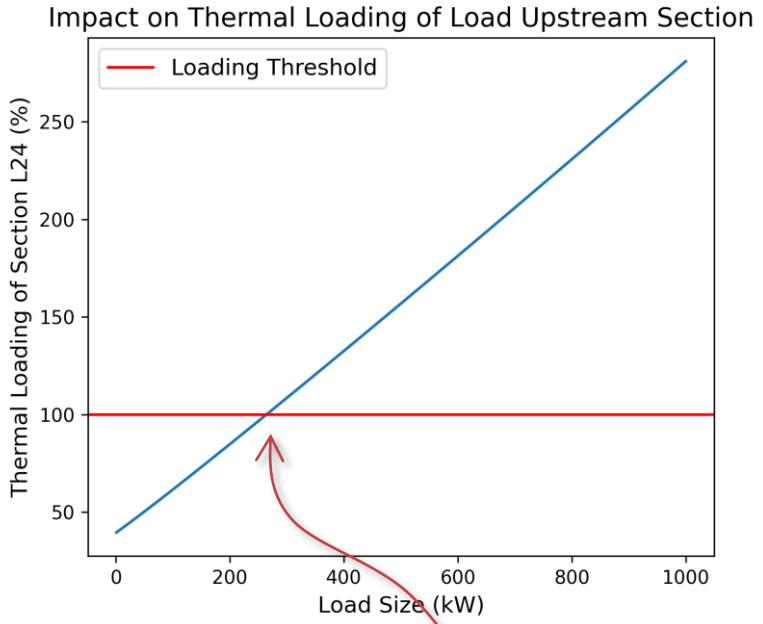
Voltage and thermal metrics have different hosting capacity limits.

Load Induced Voltage and Thermal Impacts

Check the bus and section to which the load is connected.







The penetration (0.78 MW) level at which the voltage limit of bus 4 begins to be violated.

The penetration (0.26 MW) level at which the thermal loading limit of L24 section begins to be violated.

Feeder has different hosting capacity limits for load.

Analysis

The Analysis Gets More Complex

GM
- Grid Models

DA
- Device Allocation

DT
- Device Type

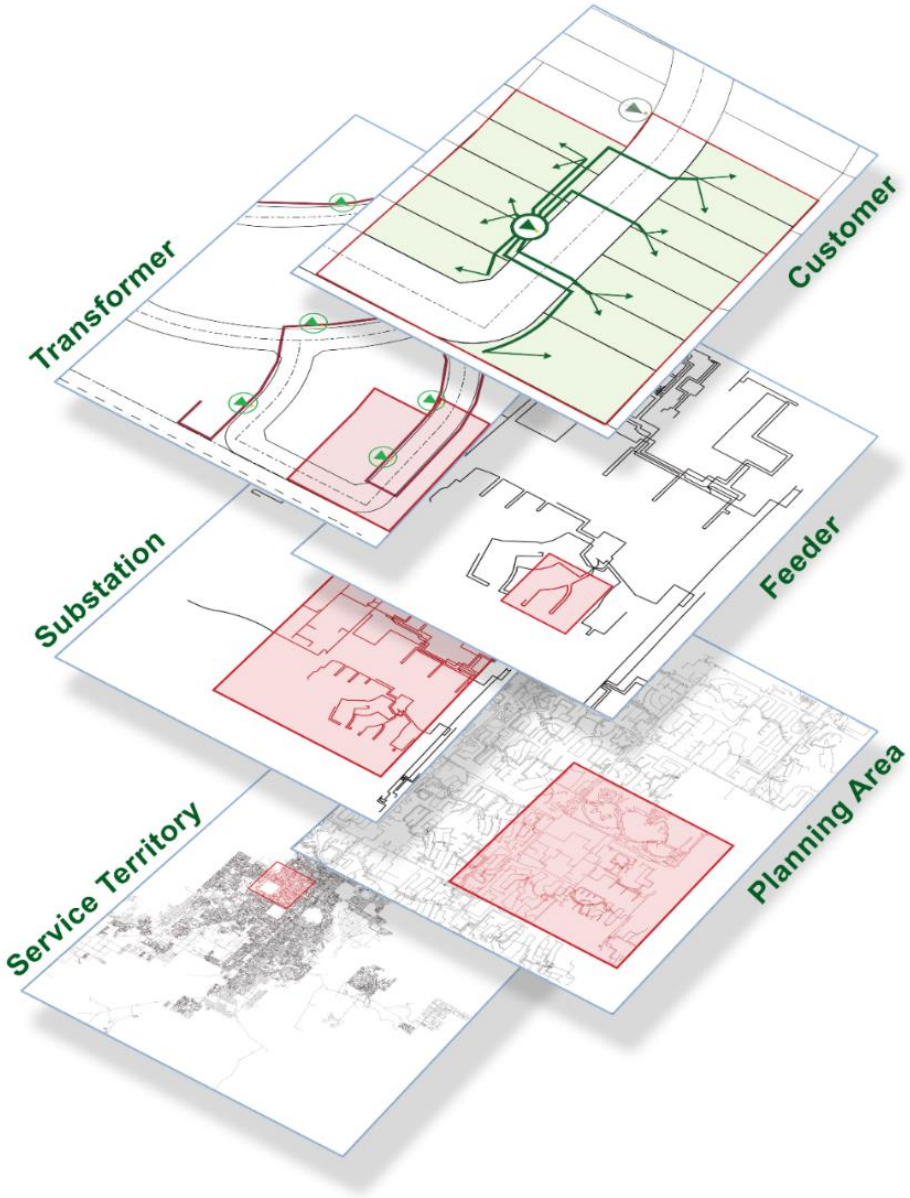
M/C
- Metrics/Criteria

IF
- Impact Factors (variables in the analysis)

M
- Methods
  - Power flow
  - Direct calculation
  - Modeless
  - Time-based

Grid Models

- Vastness of distribution utility spans service territory to individual customer
- Typical utility responsible for 100’s to 1000’s of distribution feeders
- Each feeder uniquely designed and operated to reliably serve all customers



GM
DA
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M/C
IF
M

Grid models must evolve, becoming more accurate and readily available.

Grid Model Detail

GM

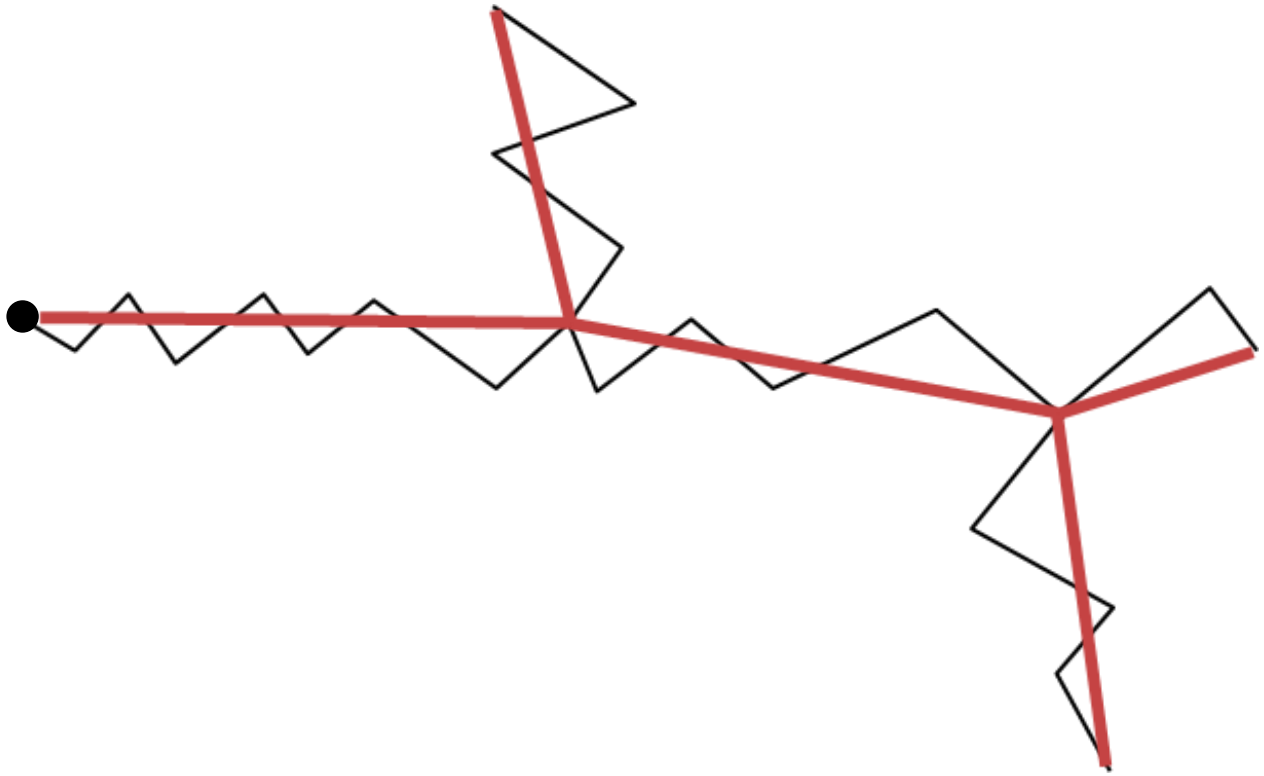
DA

DT

M/C

IF

M



Grid model detail can influence the hosting capacity results.

Device Allocation

GM
DA
DT
M/C
IF
M

- Device allocation refers to assigning or allocating future devices spatially across the distribution feeder when running the simulations.

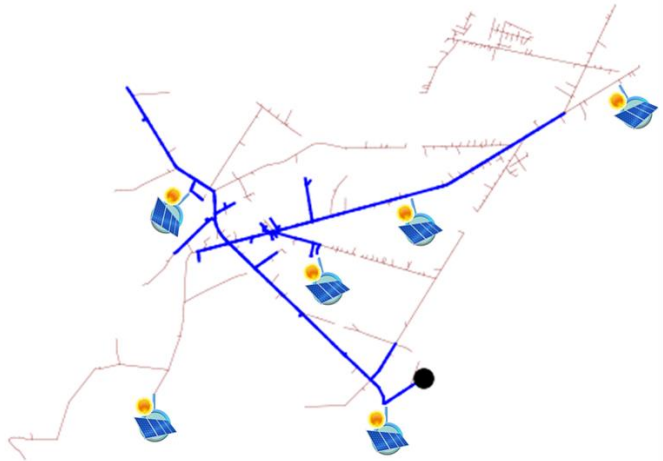
- There are two main allocation types:
  - **Centralized Allocation**
  - **Distributed Allocation**

Device Allocation

GM
DA
DT
M/C
IF
M

- **Centralized**
  - Location specific allocation
  - Feeder-wide impact observed
  - Hosting capacity describes what **each location** on the feeder **can host**
  - Resulting hosting capacity is independent of what other locations can host
  - Used to inform interconnection

- **Distributed**
  - Multiple location allocation
  - Feeder-wide impact observed
  - Hosting capacity describes what the **feeder can host**
  - Resulting hosting capacity is dependent on how the generation or load is distributed across the feeder
  - Used to inform planning



Hosting Capacity Based on Centralized Allocation

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M/C
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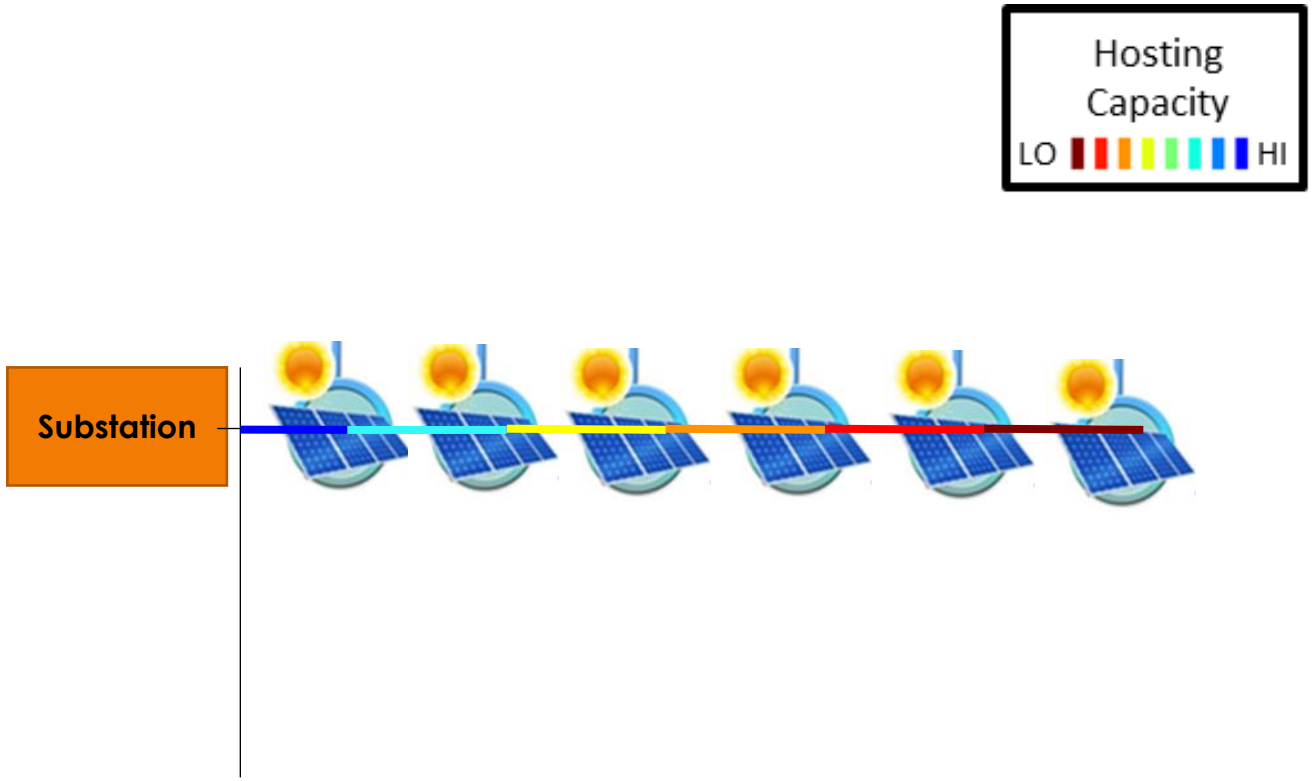
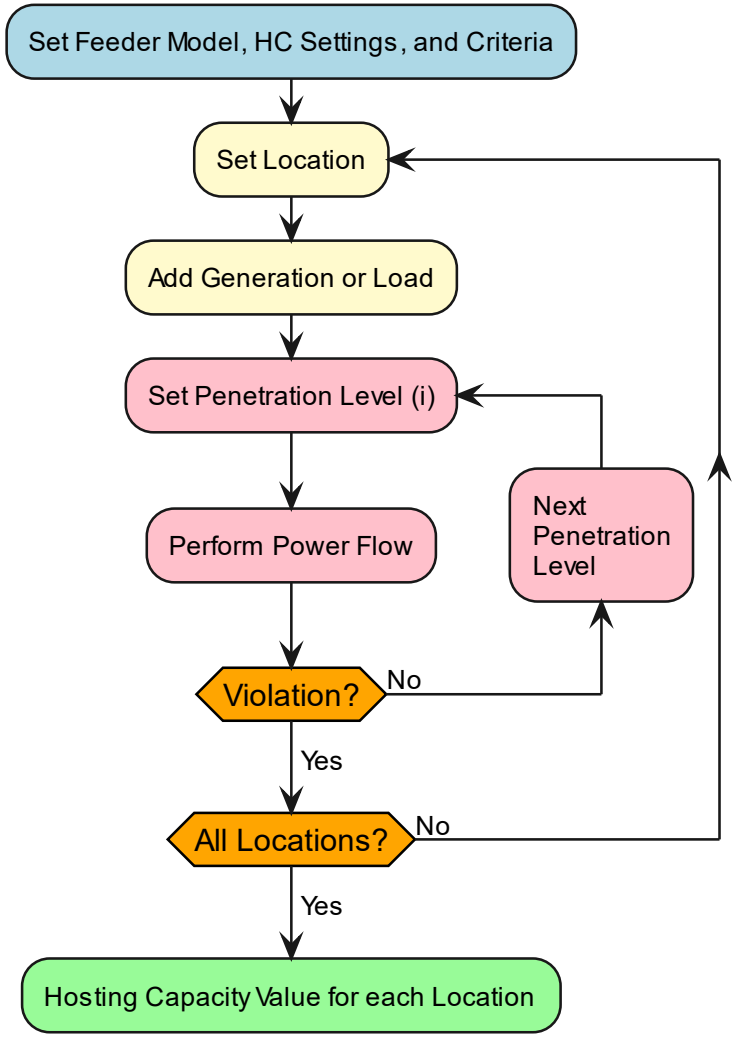


Hosting capacity is defined for the analyzed location.

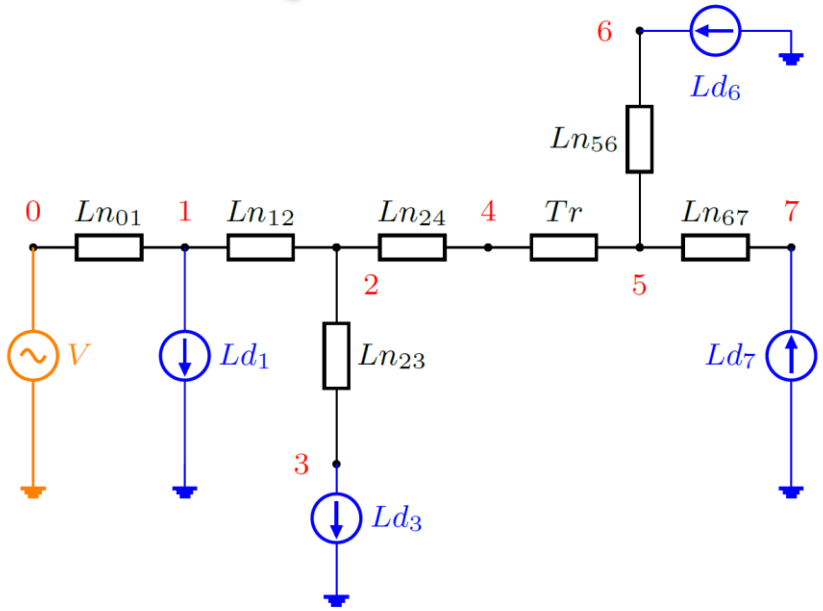
A section's hosting capacity is the range in hosting capacity between the locations analyzed.

Hosting Capacity Centralized Allocation Example



Feeder Model:
- *Offpeak load condition*

Metric:
- *Overvoltage*



Centralized Results:
- *File: AllocationType\Centralized\overvoltage.py*

Bus	Overvoltage Hosting Capacity (MW)
1	6
2	3.1
3	2.3
4	2.1
5	1.2
6	1
7	0.9

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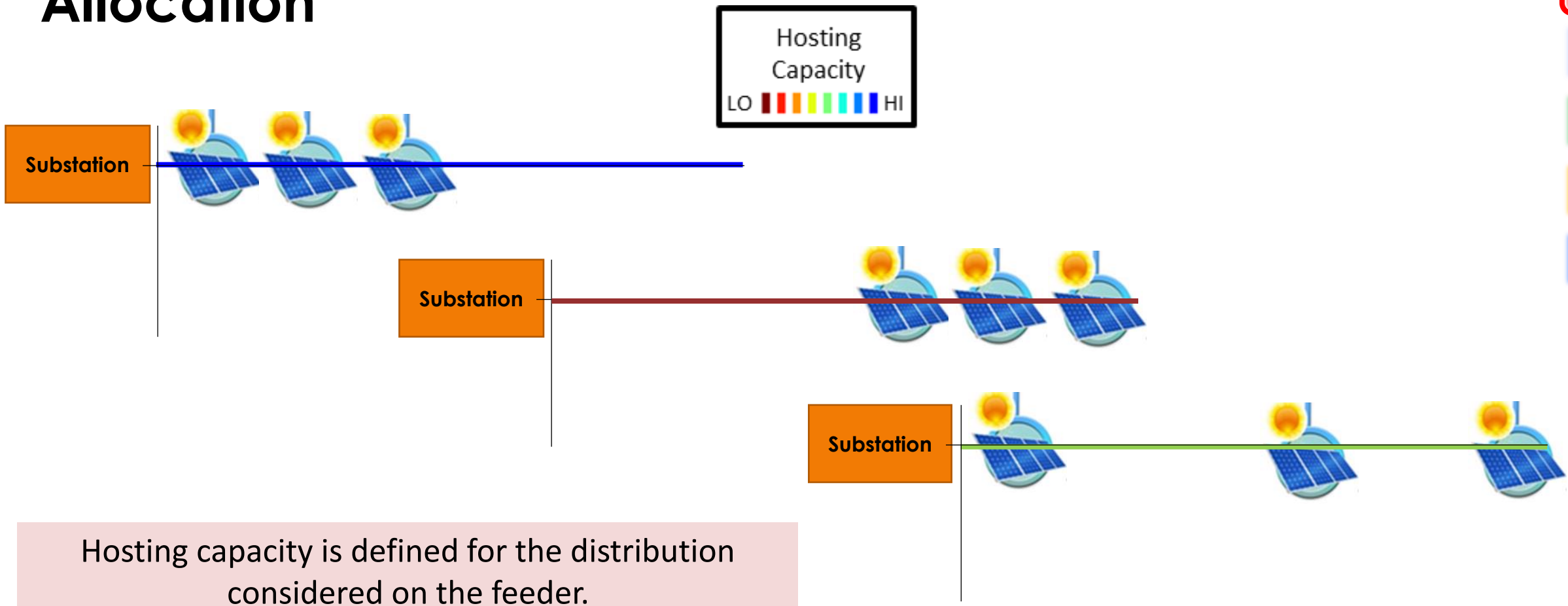
DA
DT
M/C
IF
M

Hosting Capacity Based on Fixed Location Distributed Allocation

GM
DA
DT
M/C
IF
M

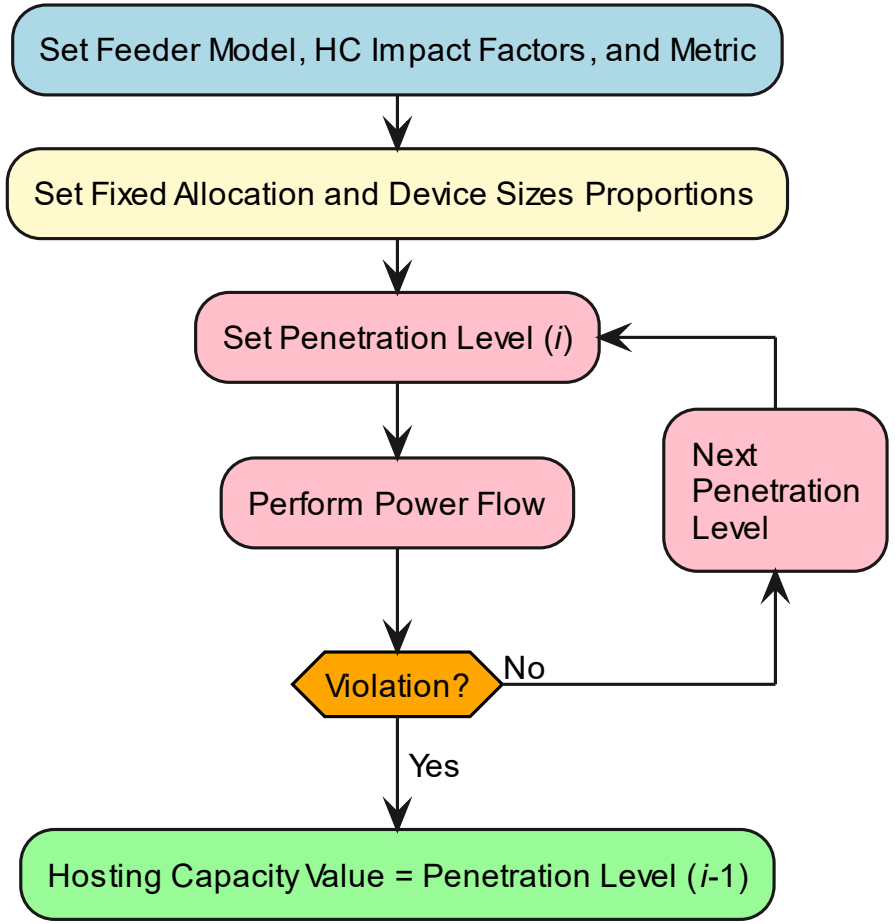


Hosting capacity is defined for the distribution considered on the feeder.

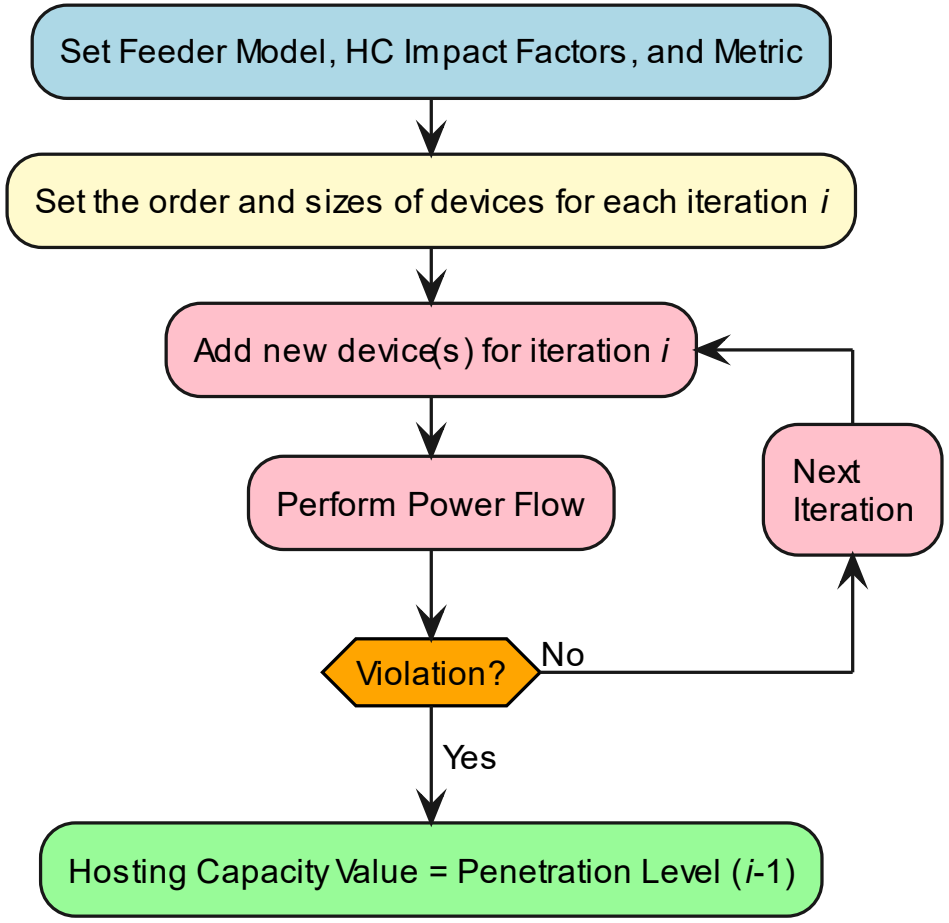
Distributed Allocation Analysis Variations

GM
DA
DT
M/C
IF
M

Fixed Location

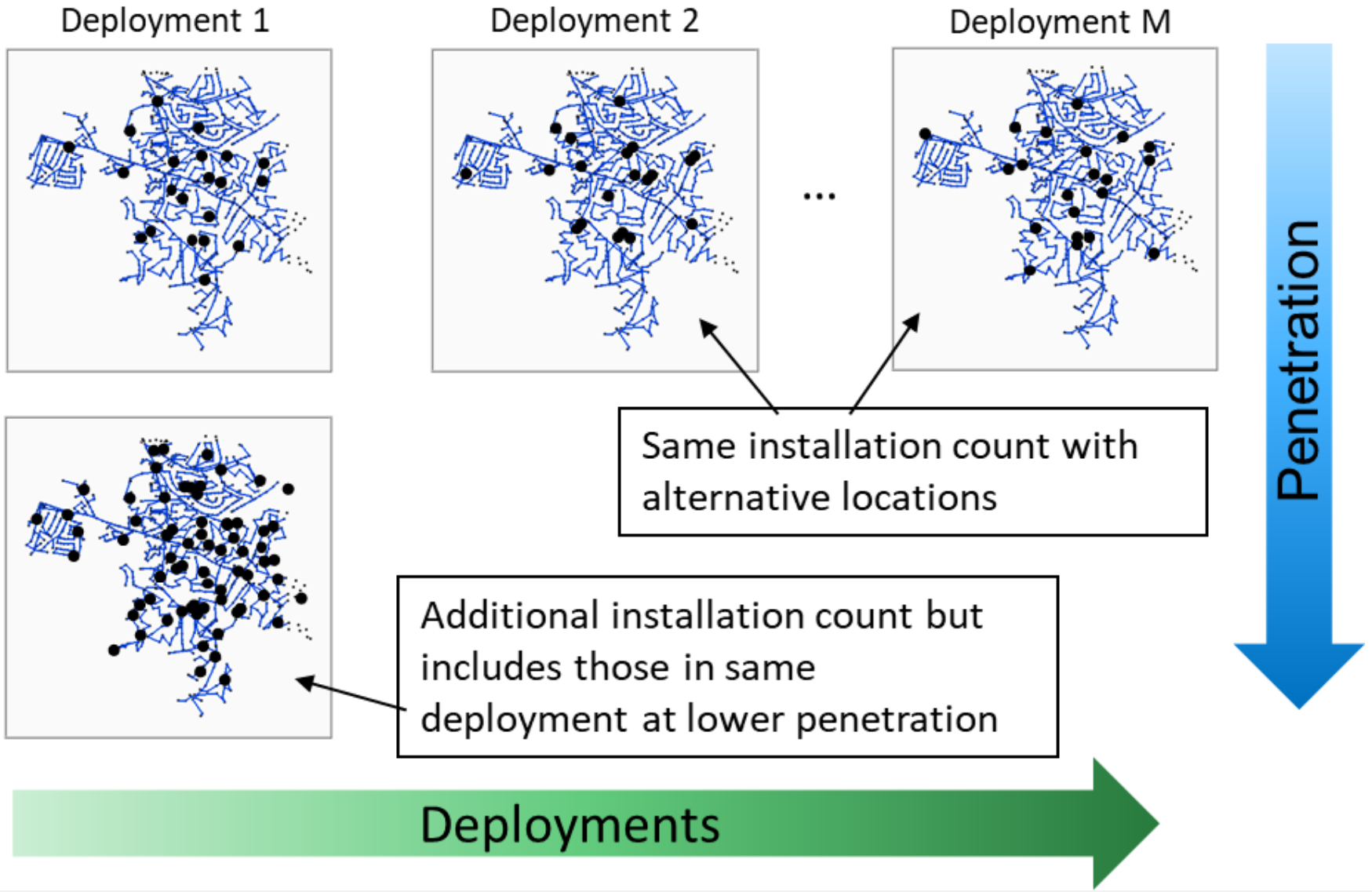


Fixed Size



Fixed Size Allocation Commonly Referred as Stochastic

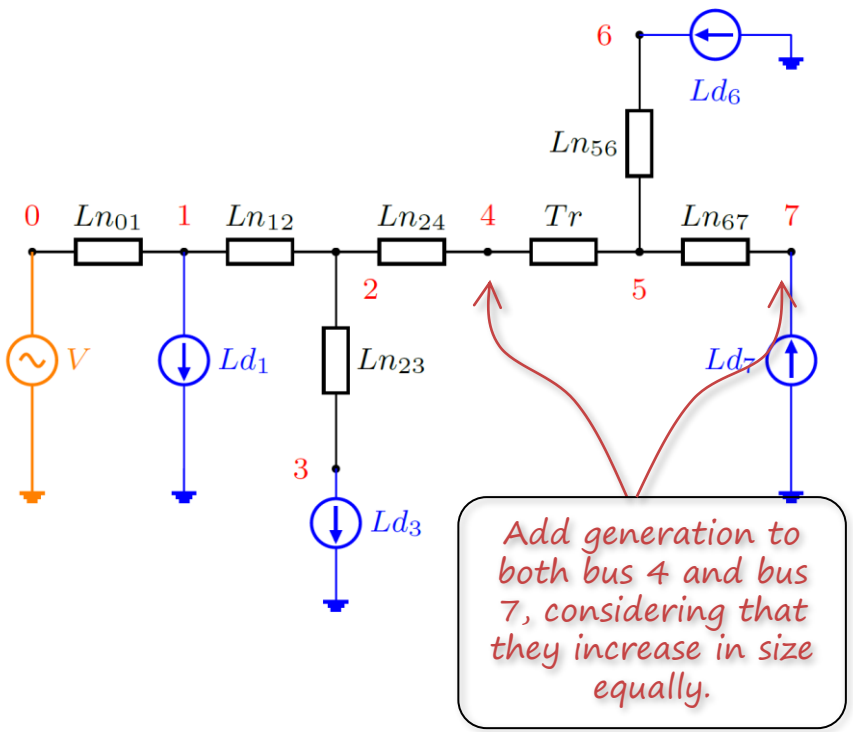
GM
DA
DT
M/C
IF
M

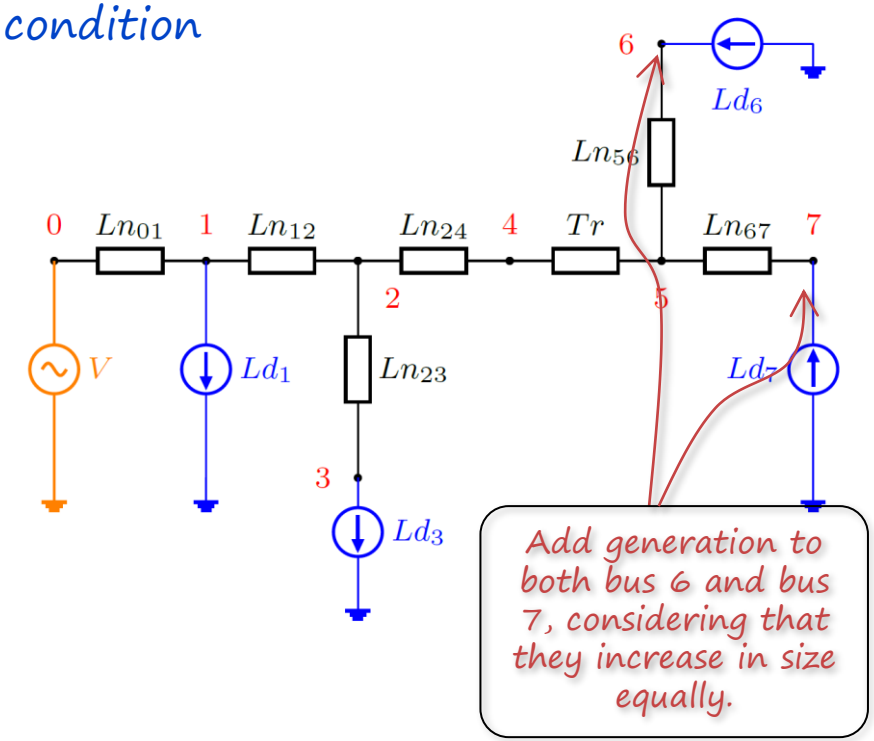


Hosting Capacity Fixed Location Example

Feeder Model:
- Offpeak load condition

Metric:
- Overvoltage

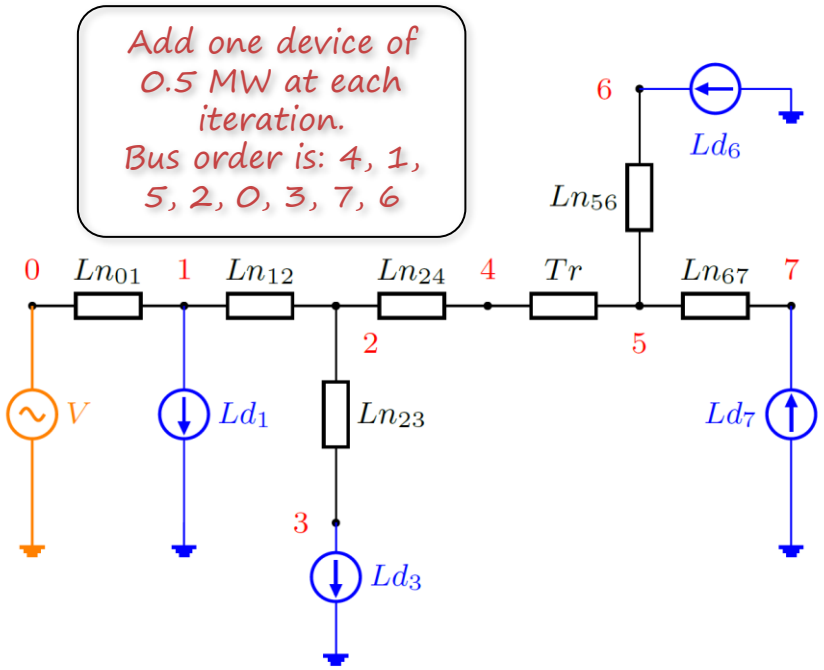


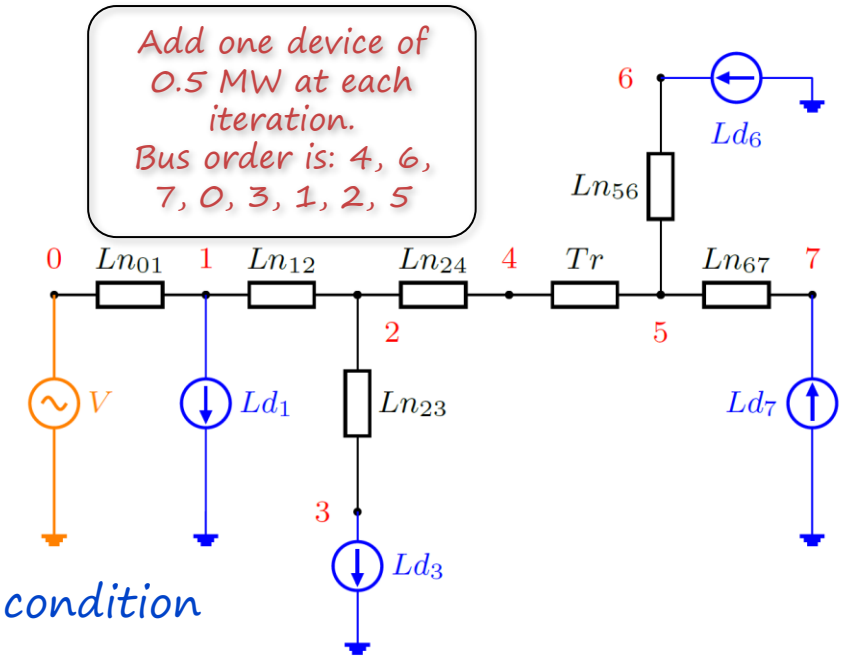


Fixed location 1:
- Hosting capacity of 1.3 MW
- Each generator with 1.3/2 MW
- File: AllocationType\Distributed\FixedLocation\fixed_location_1.py

Fixed location 2:
- Hosting capacity of 1.0 MW
- Each generator with 1.0/2 MW
- File: AllocationType\Distributed\FixedLocation\fixed_location_2.py

Hosting Capacity Fixed Size Example





Feeder Model:
- Offpeak load condition

Metric:
- Overvoltage

Fixed size 1:
- Hosting capacity of 2.5 MW
- Generator at bus 4, 1, 5, 2, and 0 with 0.5 MW
- File: AllocationType\Distributed\FixedDeviceSize\fixed_device_size_1.py

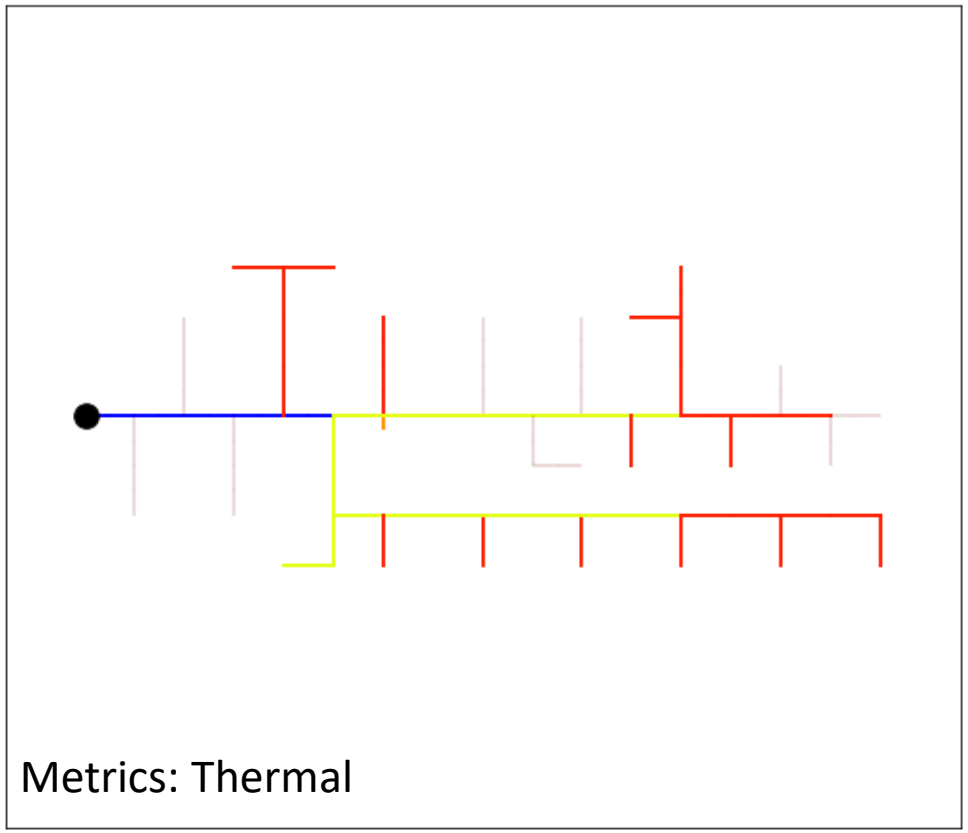
Fixed size 2:
- Hosting capacity of 1.0 MW
- Generator at bus 4, and 6 with 0.5 MW
- File: AllocationType\Distributed\FixedDeviceSize\fixed_device_size_2.py

GM
DA
DT
M/C
IF
M

Hosting Capacity Based on Device Type

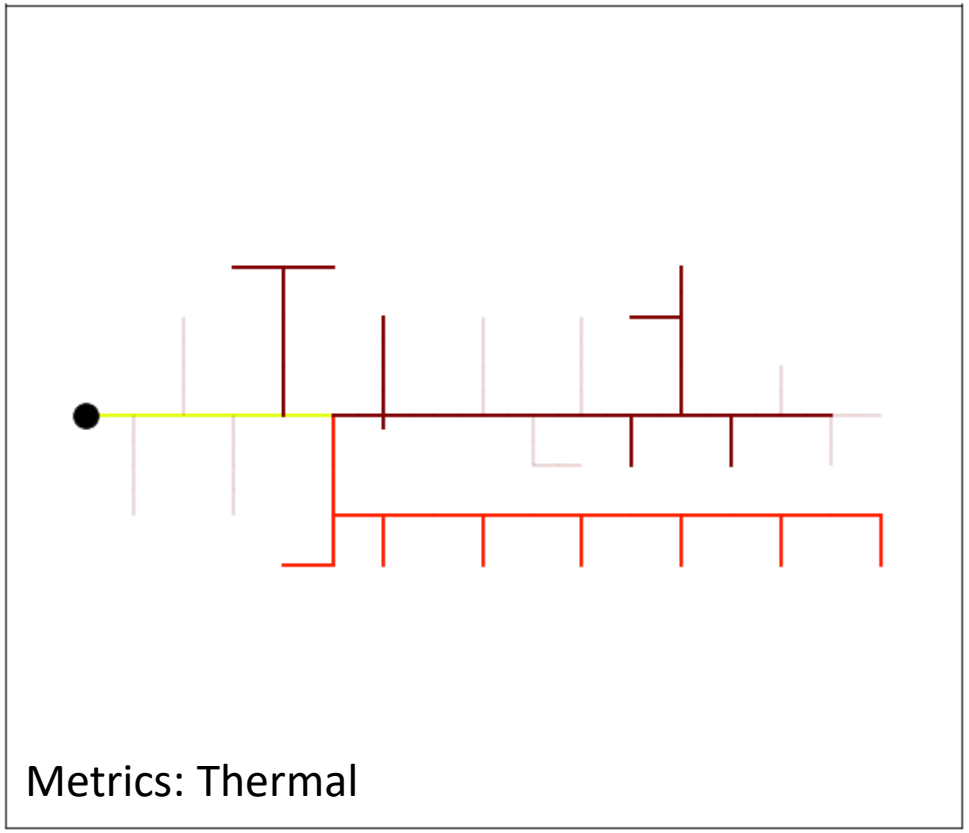
GM
DA
DT
M/C
IF
M

Generation



Metrics: Thermal

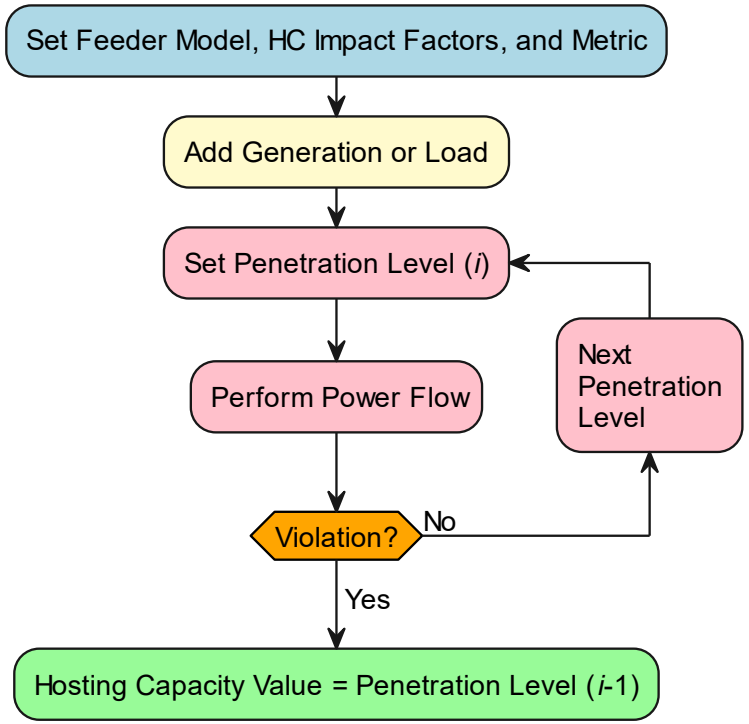
Load



Metrics: Thermal

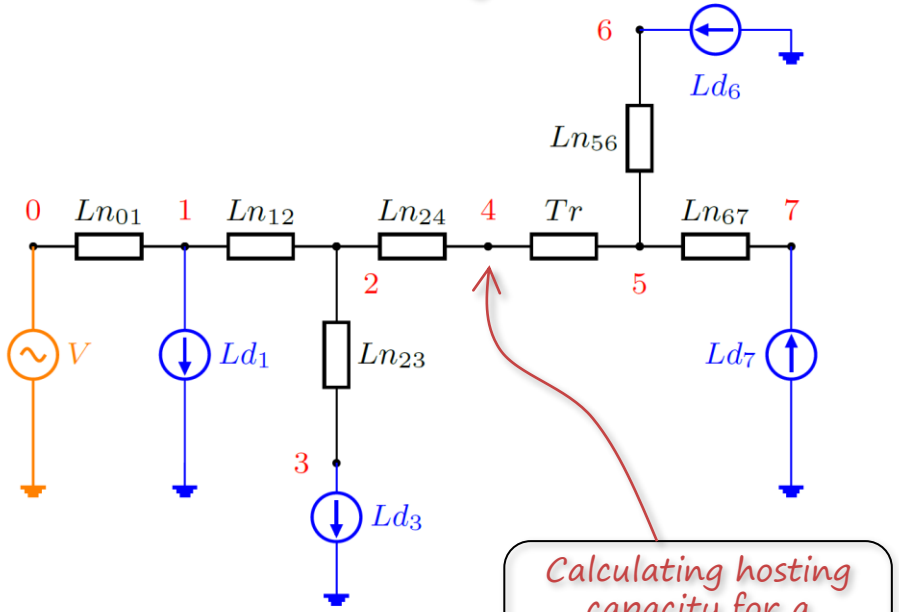
The device type can either be a generation, load, or both.

Hosting Capacity Device Type Example



Feeder Model:
- *Offpeak load condition*

Metric:
- *Thermal loading*



Calculating hosting capacity for a future/new generation/load at bus 4

***Generation** device type:*
- *Hosting capacity of 0.4 MW*
- *File: DeviceType\gen_thermal.py*

***Load** device type:*
- *Hosting capacity of 0.2 MW*
- *File: DeviceType\load_thermal.py*

Hosting Capacity Dependent on Device Type

Metrics/Criteria

- A metric or criteria refers to specific power system parameter for evaluating hosting capacity.
- Exceeding defined thresholds in these metrics indicates reaching the hosting capacity limit.

Category	*Metric*	*Threshold*
Voltage	Magnitude	Feeder voltage at any location not to go above or below a specified voltage limit
	Deviation	Feeder voltage at any location not to change by more than a specified percent
	Regulator Deviation	Feeder voltage observed at any regulating device not to change by more than a specified amount of the regulating devices bandwidth
	Unbalance	Feeder voltage unbalance at any location not to exceed a specified percent
Thermal	Congestion	Power flow through any element toward or away from the feeder head not to exceed a percentage of the elements normal rating
	Reverse Power Flow	Power flow through specified elements not to flow in the direction toward the feeder head
Protection	Element Fault Current	Feeder fault current not to increase by more than a percentage of fault current prior to generation
	Sympathetic Breaker Relay Tripping	Breaker zero sequence fault current not to exceed a specified amount in amps
	Relay Reduction of Reach	Breaker fault current not to decrease by more than a percentage of fault current prior to generation
	Unintentional Islanding	Power flow through specified elements not to be reduced by more than a percentage of minimum load power flow
	Ground Fault Overvoltage (3V0)	Power flow through substation not to be reduced by more than a percentage of minimum load power flow
PQ & Reliability	Operational Flexibility	Maintain ability to reconfigure based on parallel feeder limits
	Flicker	The maximum allowable Pst value

GM
DA
DT
M/C
IF
M

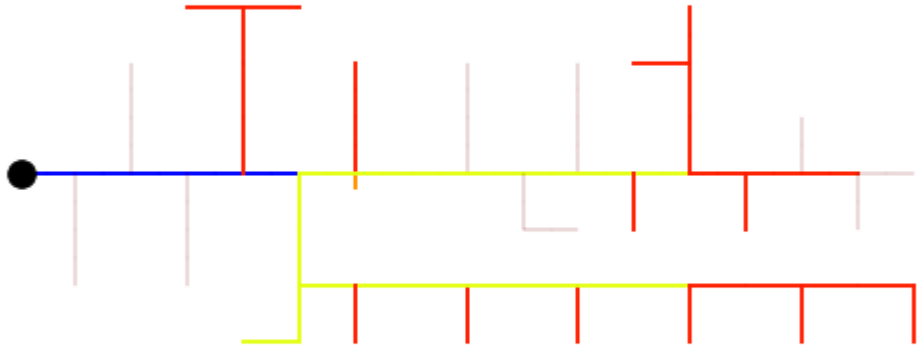
Hosting capacity can be defined for any or all of the metrics shown.

Hosting Capacity Based on Metrics/Criteria

GM
DA
DT
M/C
IF
M

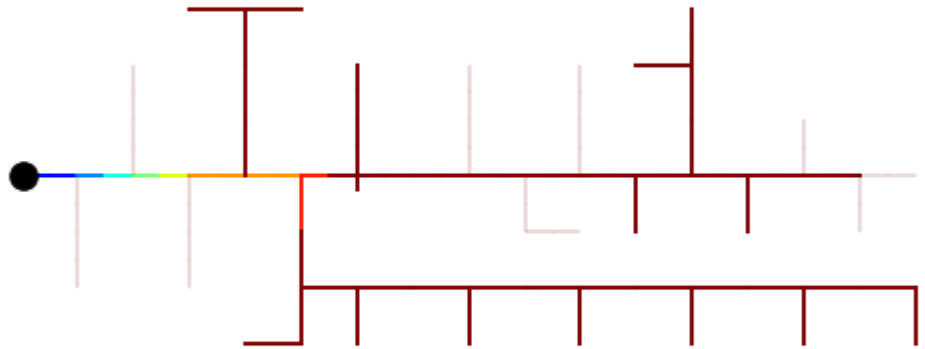
Metrics: Thermal

DRIVE



Metrics: Thermal and Voltage

DRIVE

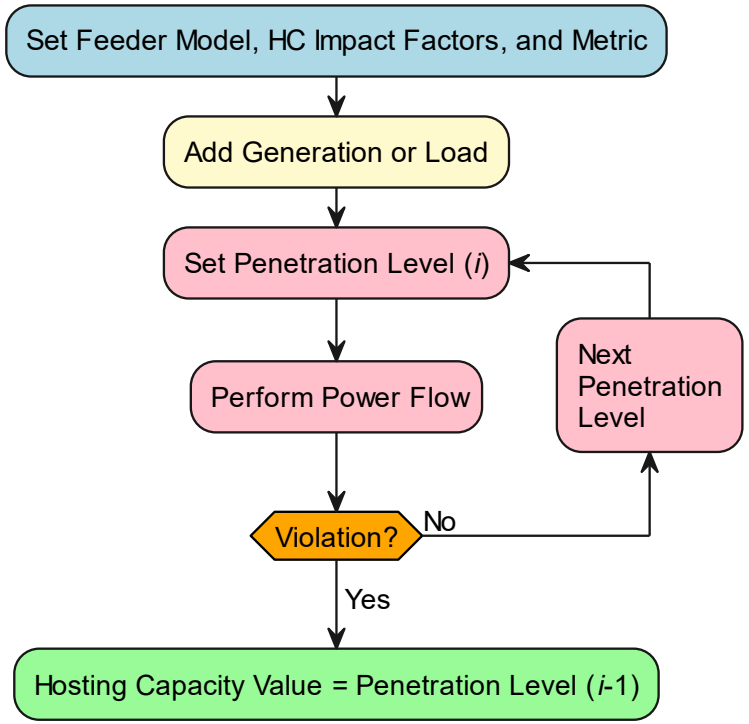


< 1.25 MW
1.25-2.5 MW
2.5-3.75 MW
3.75-5.0 MW
5.0-6.25 MW
6.25-7.5 MW
7.5-8.75 MW
> 8.75 MW

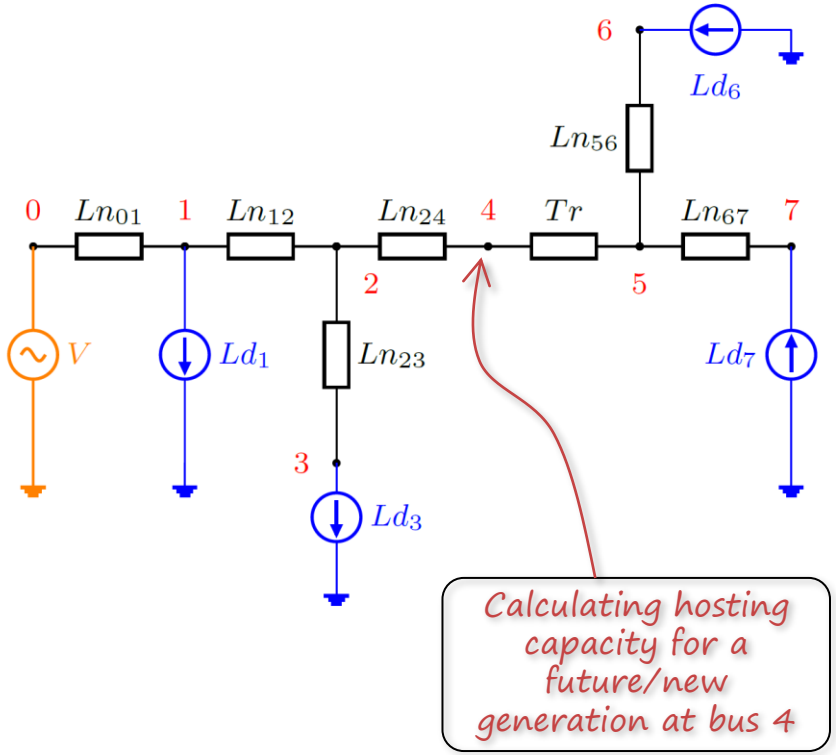
Consideration of Multiple Metrics

Hosting Capacity Metrics/Criteria Example

GM
DA
DT
M/C
IF
M



Feeder Model:
- Offpeak load condition



Overvoltage metric:
- Hosting capacity of 2.1 MW
- File: Metric\overvoltage.py

Thermal loading metric:
- Hosting capacity of 0.4 MW
- File: Metric\thermal_gen.py

Hosting Capacity Dependent on Metrics

Impact Factors

- Impact factors are the various characteristics of the distribution grid and the future device that influence the hosting capacity results.

- **Grid Impact Factors**: Configuration, voltage regulation, load level, etc.

- **Device Impact Factors**: Magnitude of output, power factor, etc.

GM
DA
DT
M/C
IF
M

Impact Factors and Recommendations on How to Incorporate Them When Calculating Hosting Capacity. EPRI, Palo Alto, CA: 2018. 3002013381.

Hosting Capacity Based on Impact Factor

Configuration

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DA

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M/C

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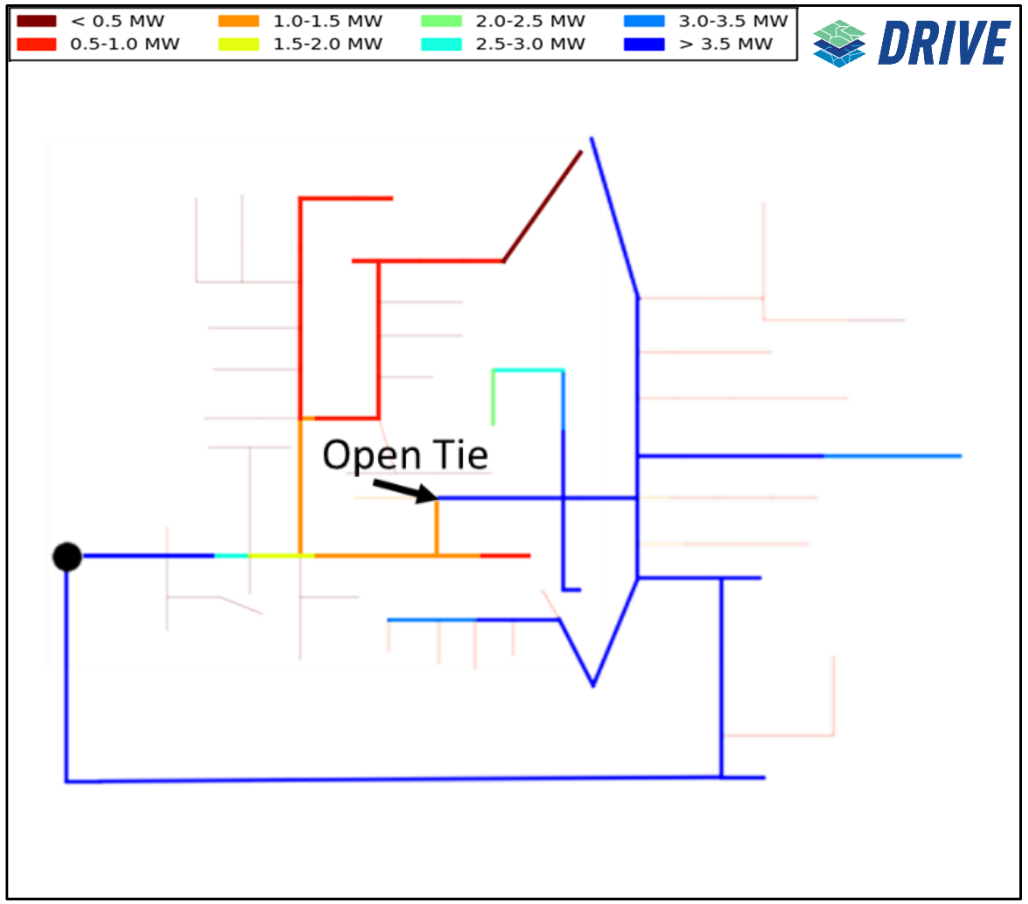
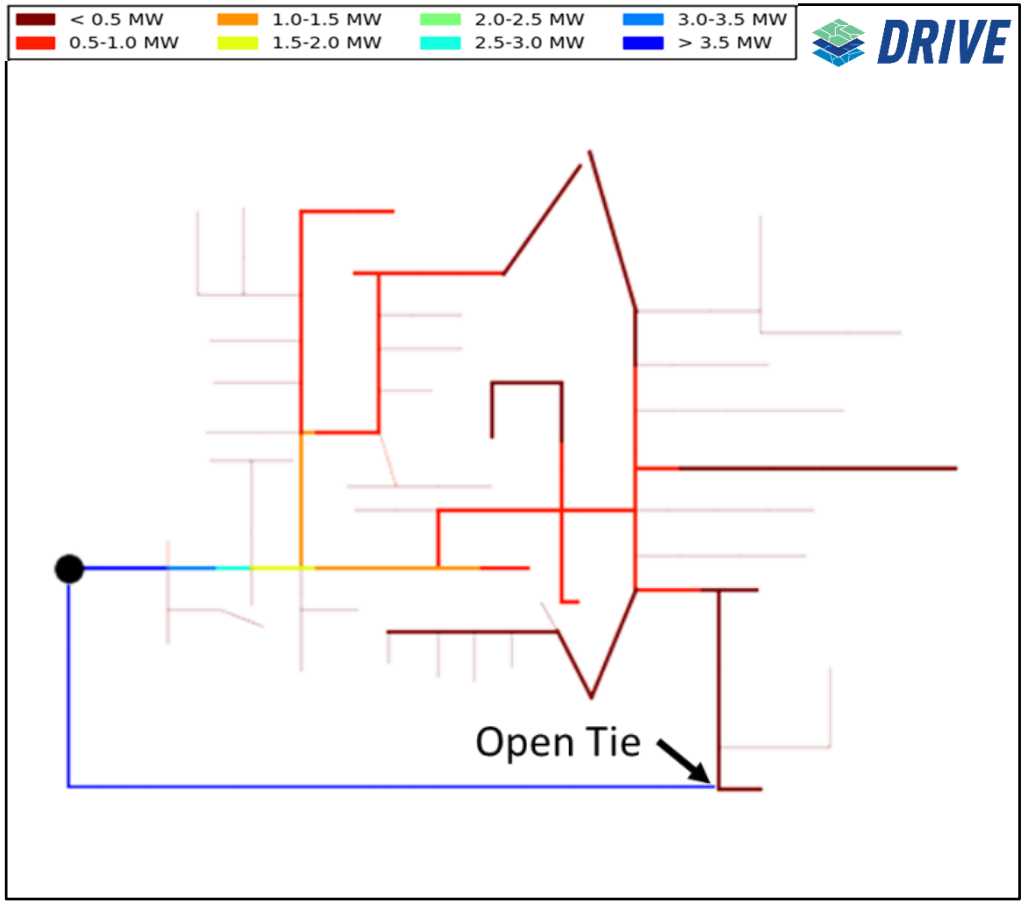
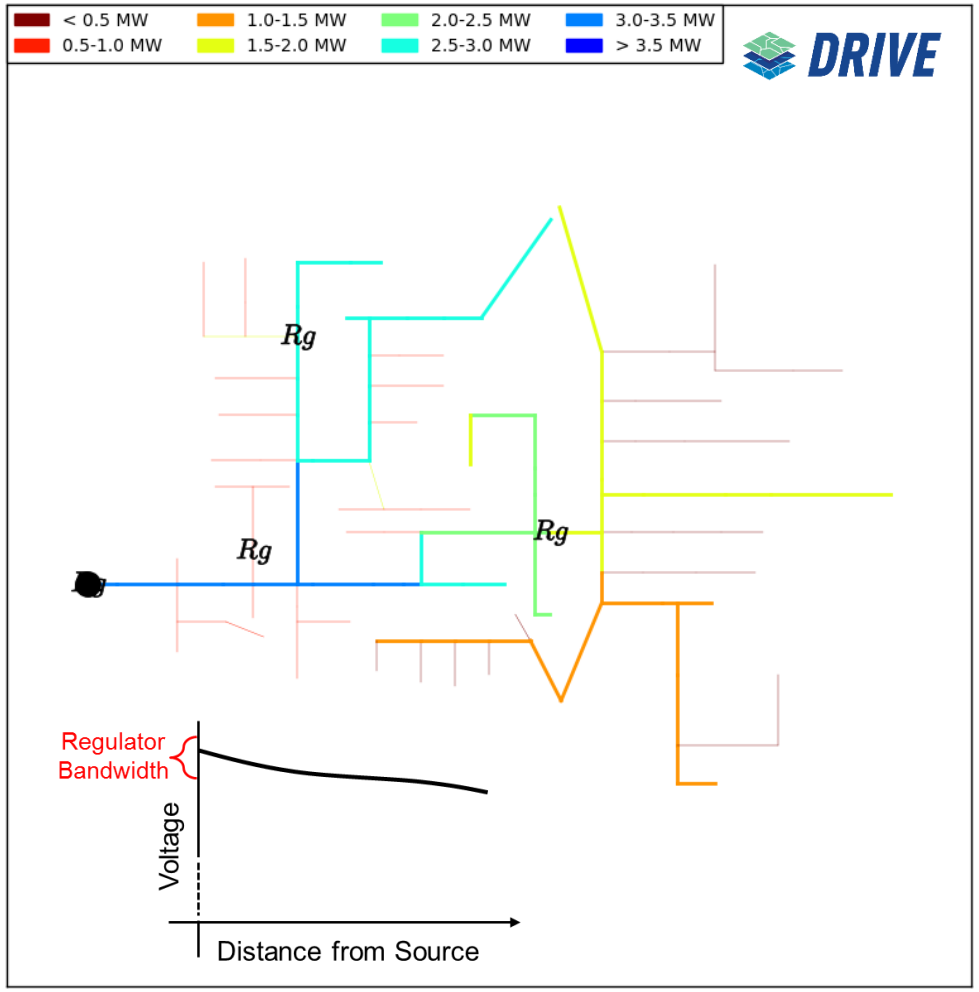


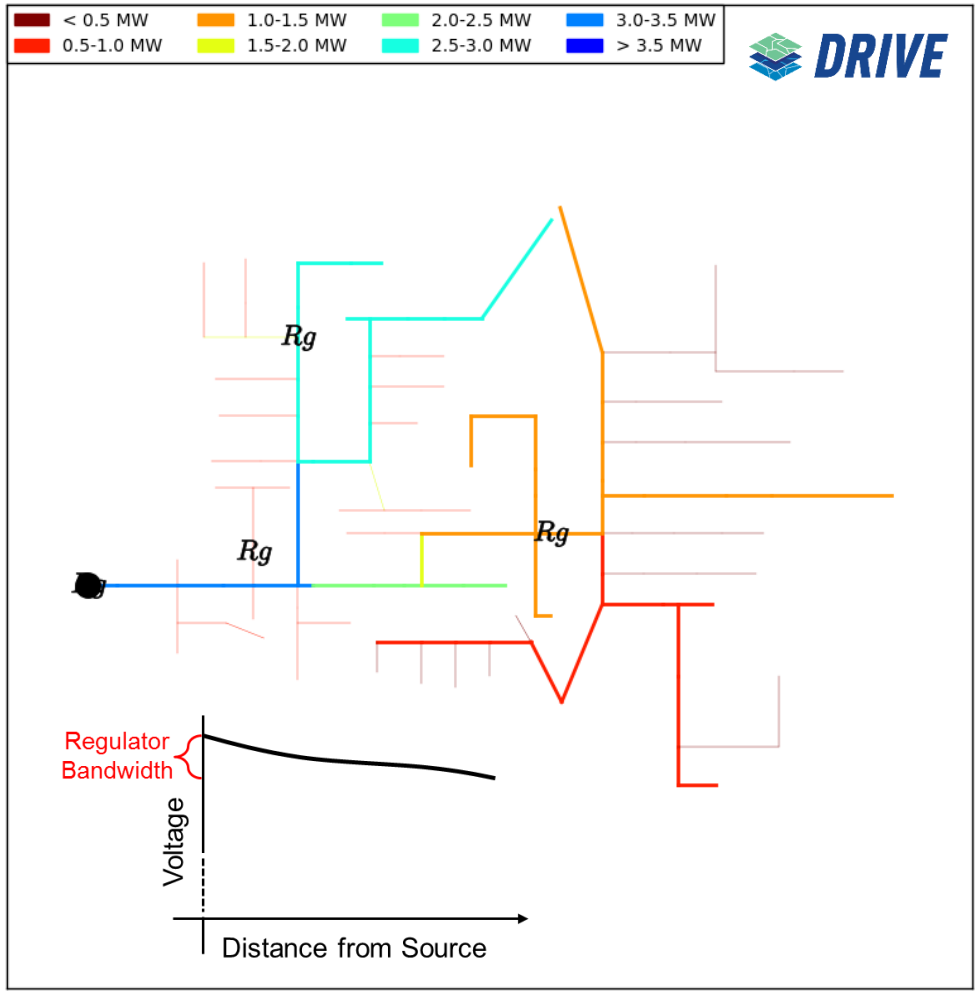


Consideration for Alternative Configuration

Hosting Capacity Based on Impact Factor

Voltage Regulation





Consideration for Alternative Tap Position

GM
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M/C
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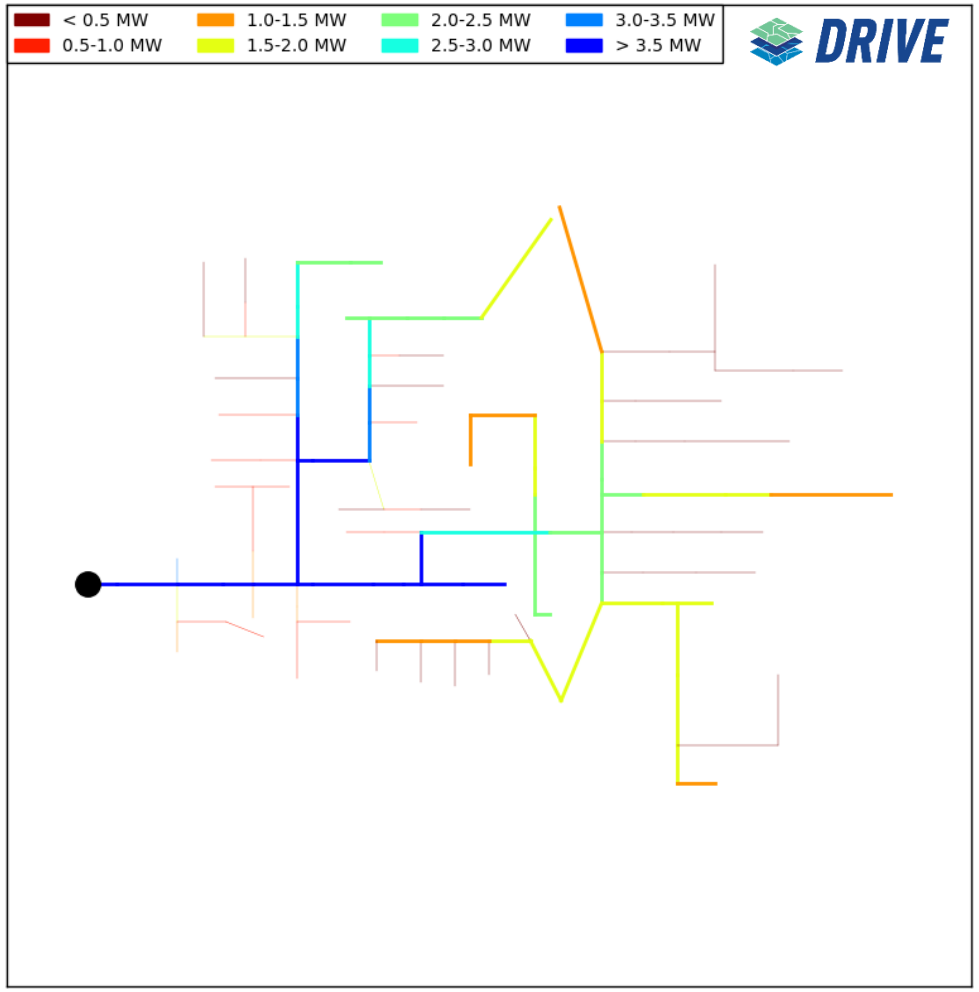
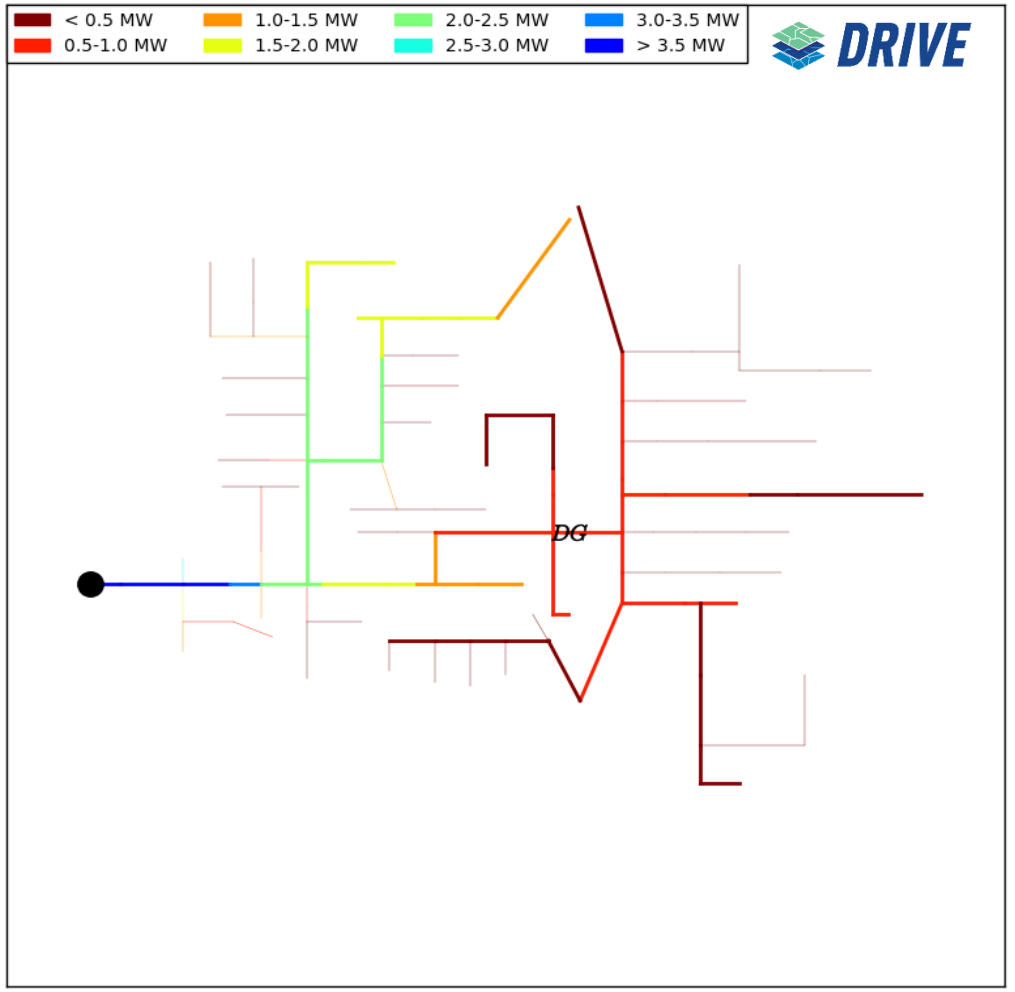
Hosting Capacity Based on Impact Factor

Connected Distributed Generation





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IF

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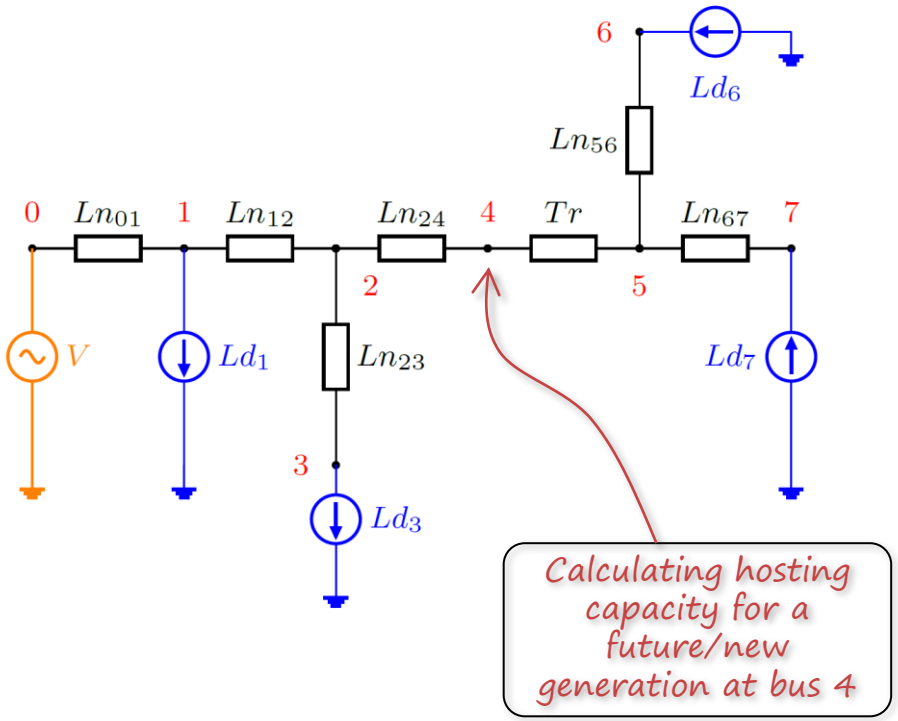
Considering Connected Generation

Hosting Capacity Impact Factor Example

Metric:
- Overvoltage



Offpeak load condition:
- Hosting capacity of 2.1 MW
- File: ImpactFactors\base_case.py

Offpeak load condition and **existing generation** at bus 2 of 1 MW:
- Hosting capacity of 1.4 MW
- File: ImpactFactors\existing_gen.py

Peak load condition:
- Hosting capacity of 2.9 MW
- File: ImpactFactors\load_level_condition.py

Offpeak load condition and **future generation** with 0.95 power factor inductive:
- Hosting capacity of 2.7 MW
- File:ImpactFactors\new_device_pf.py

GM
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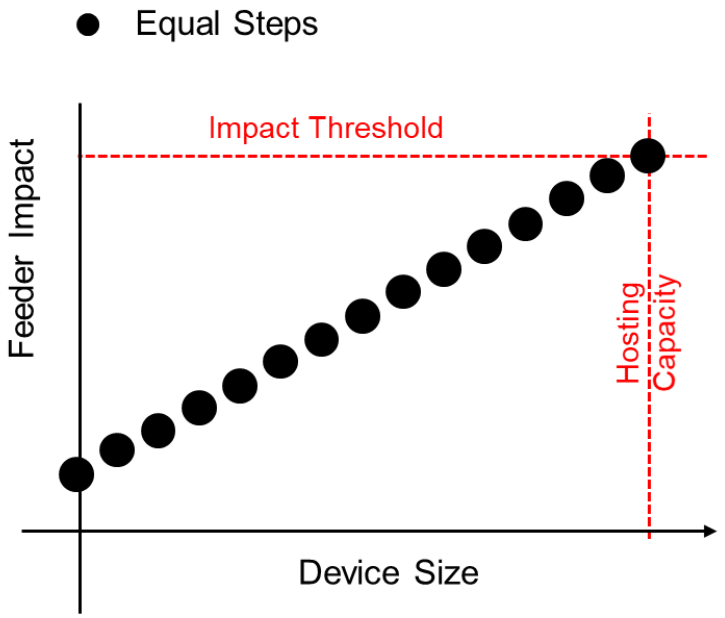
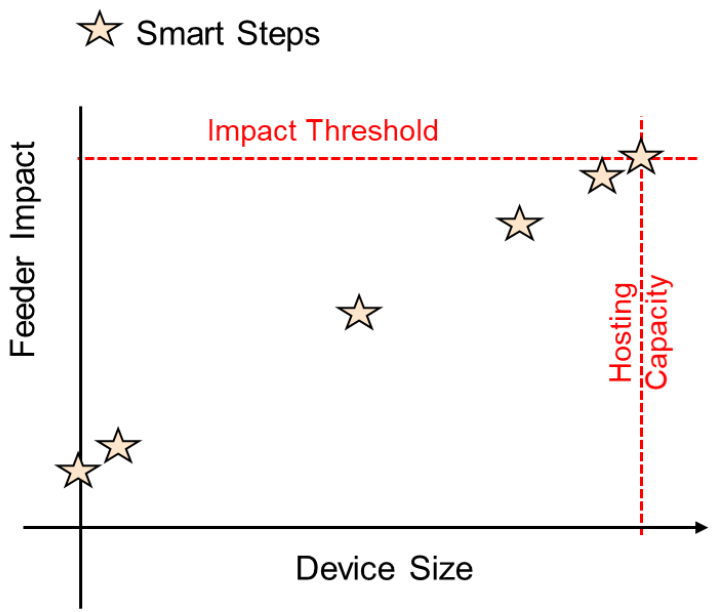
M/C
IF
M

Hosting Capacity Dependent on Impact Factors

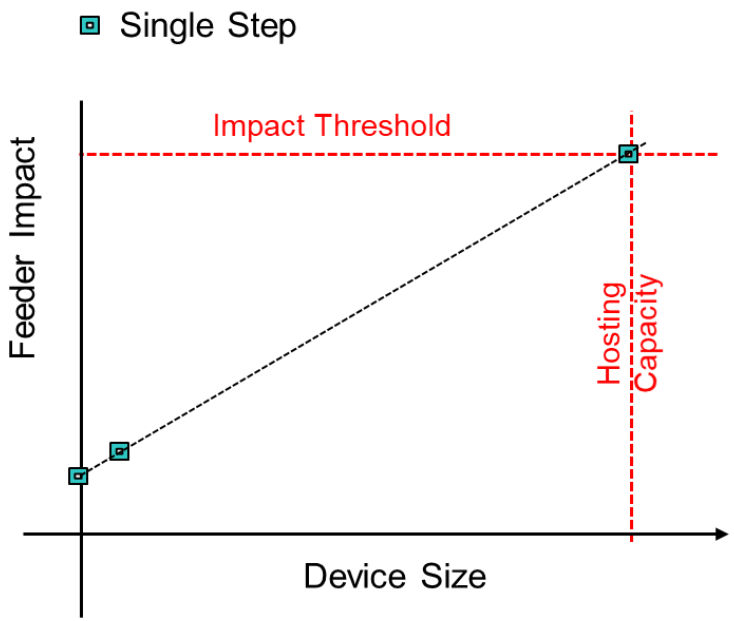
Methods | Power Flow Solution vs Direct Calculation



Power flow solutions at equal penetration steps



Power flow solutions reduced by taking smart penetration steps



Two power flow solutions allow hosting capacity to be approximated with direct calculation

GM
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IF
M

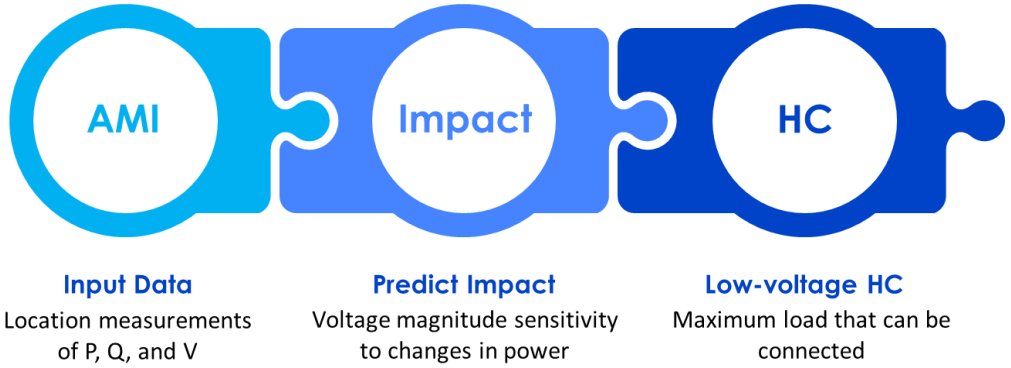
Methods | Modeless

GM DA DT M/C IF M

AMI data-driven method

Model-free **voltage impact** locational hosting capacity

- No secondary model available
- AMI measurements of voltage, active and reactive power available at location
- No power flow needed



Methodology

1. Estimate the **sensitivity of voltage magnitude to changes in power** at a customer location from its smart meter data
2. **Apply that sensitivity to predict the potential voltage impact**s of load/gen and determine the HC.

Generation/load hosting capacity

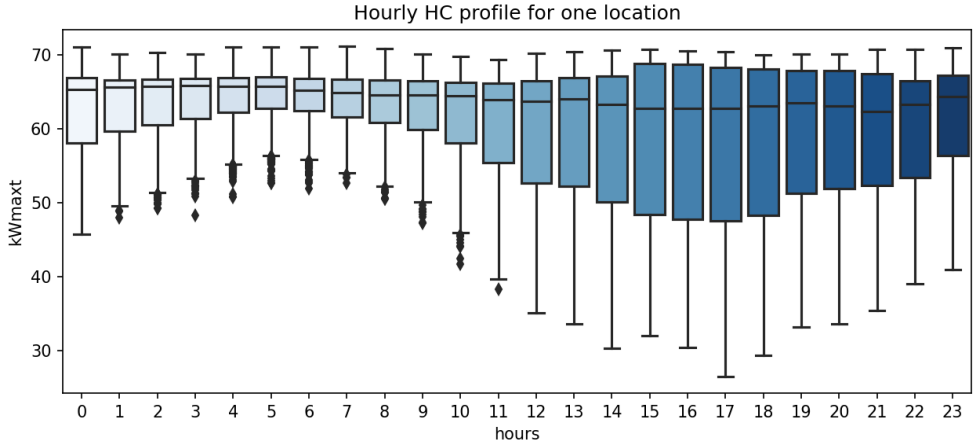
1. Load HC:

$$kW_{max}(t) = (V(t) - V_{limit})/\sigma_{Final}$$

2. Generation HC:

$$kW_{max}(t) = (V_{limit} - V(t))/\sigma_{Final}$$

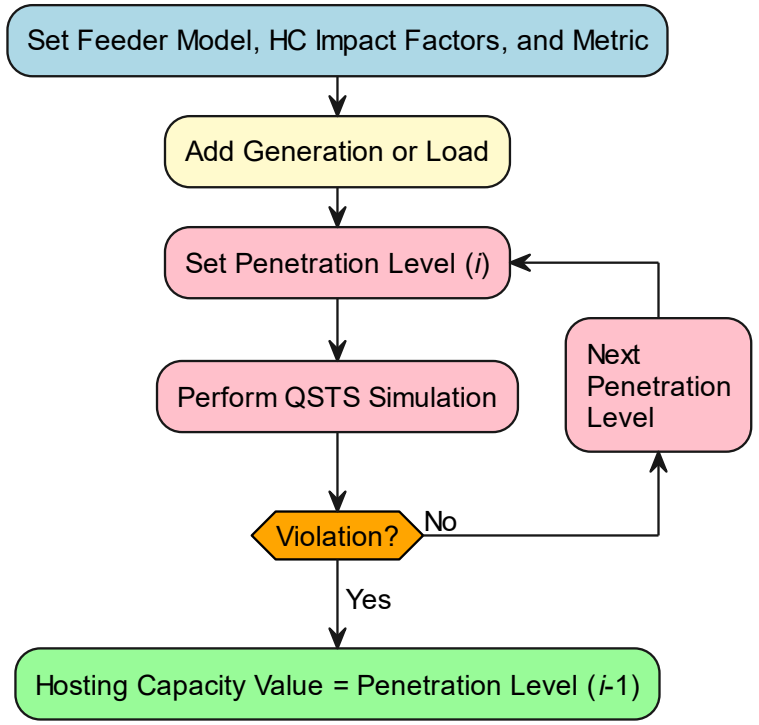
sensitivity



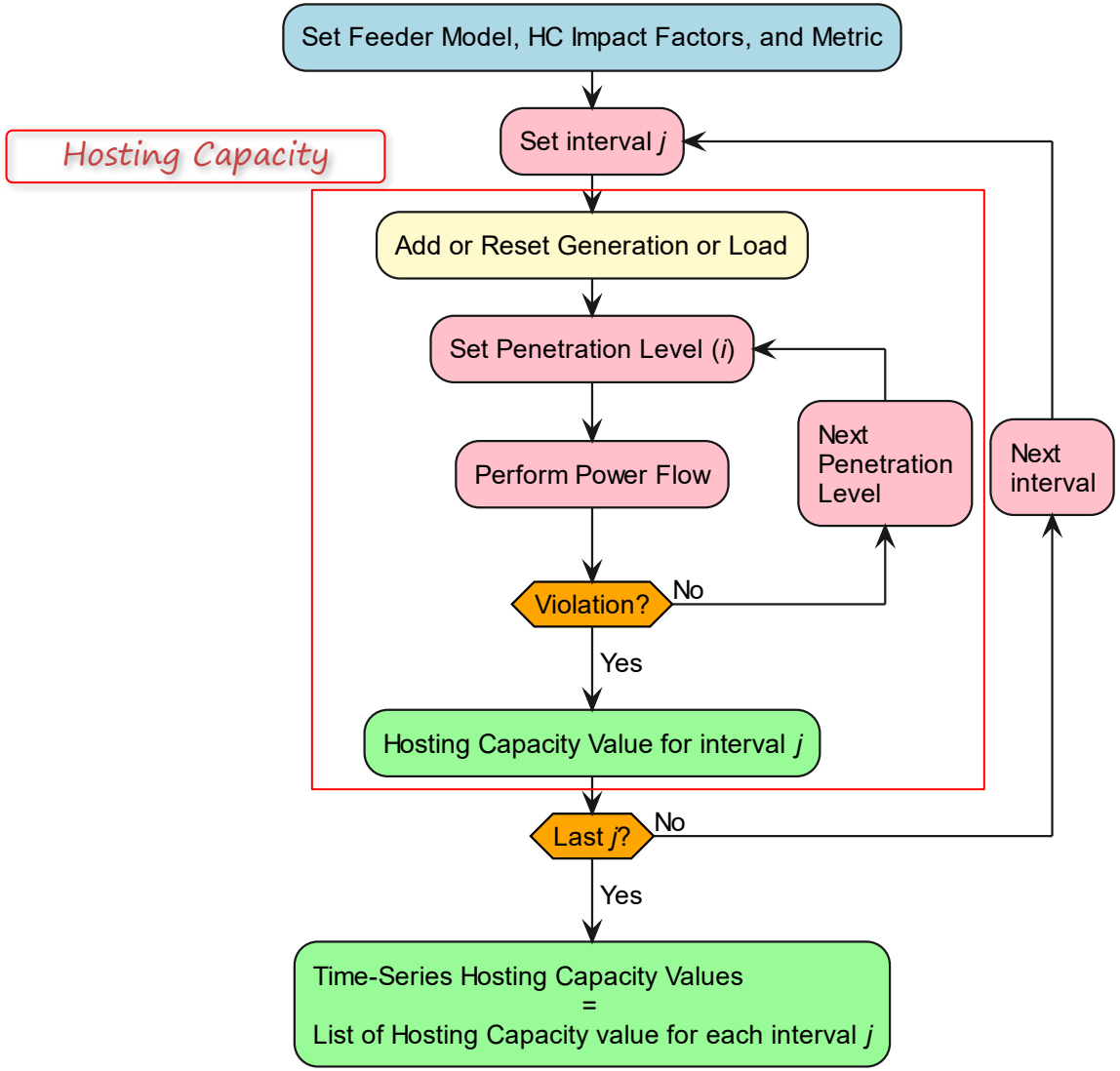
Hosting capacity derived by voltage sensitivity to power

Methods | Time-Based

QSTS Hosting Capacity



Time-Series Hosting Capacity



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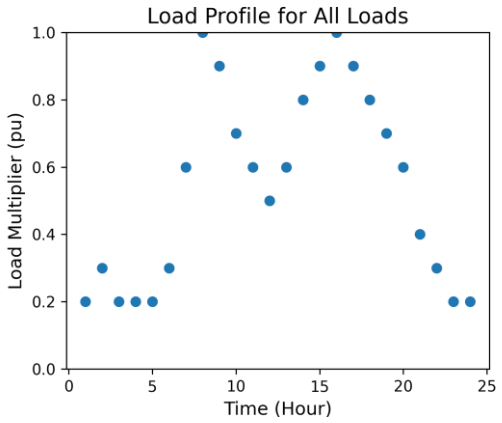
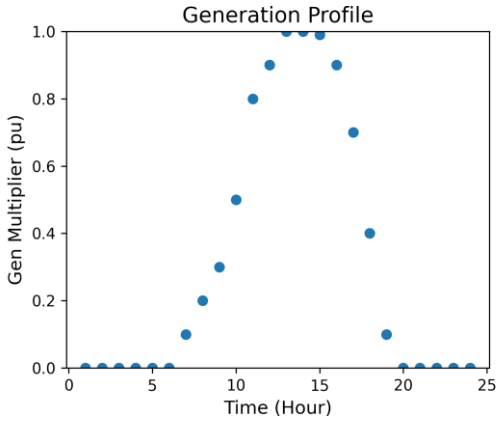
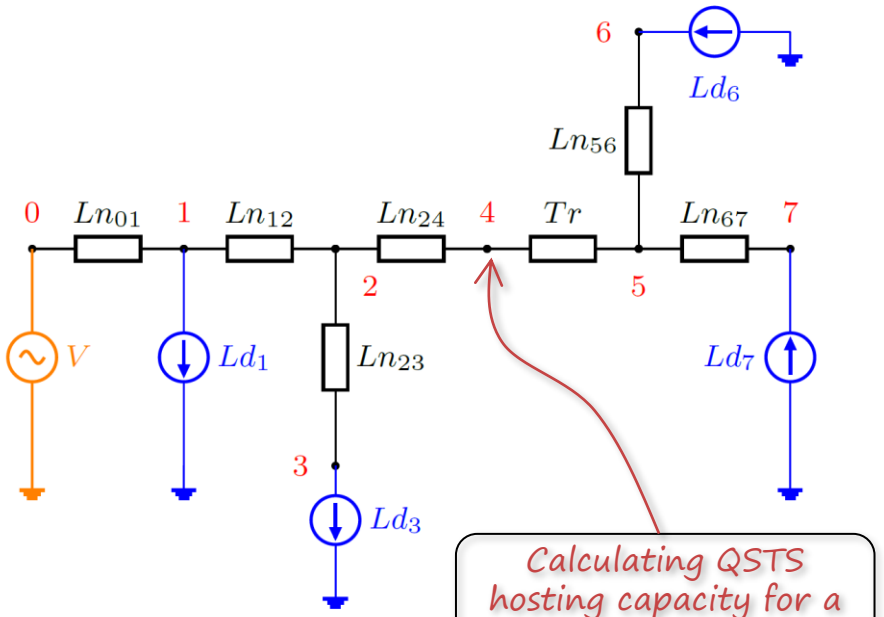
M/C
IF
M

QSTS Hosting Capacity Example

Metric:
- *Overvoltage*

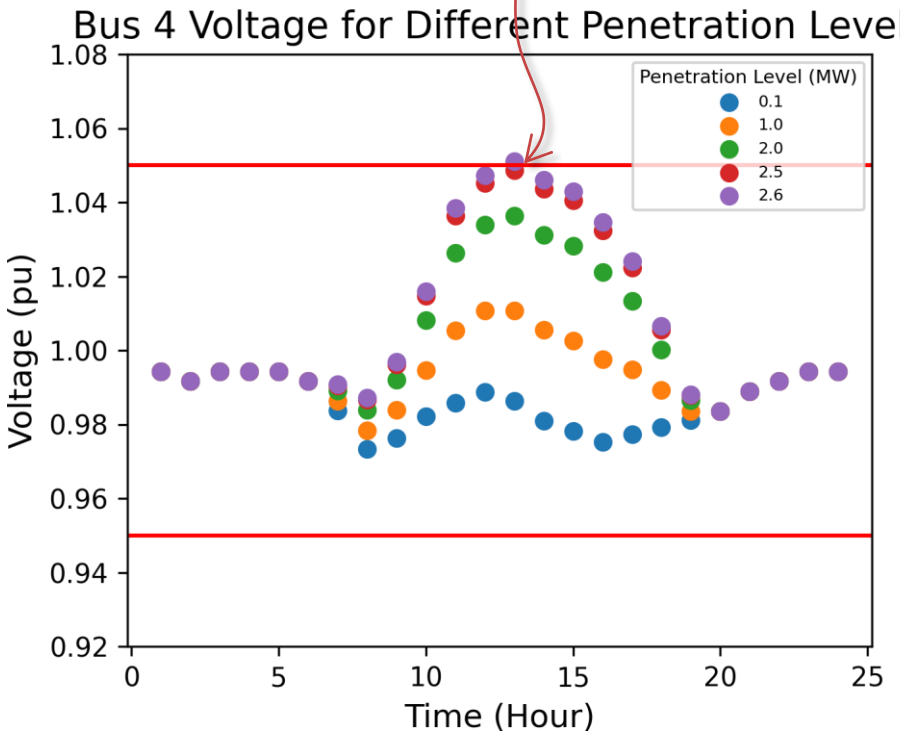






Calculating QSTS hosting capacity for a future/new generation at bus 4

2.6 MW violates overvoltage limit at hour 13. Hosting capacity of 2.5 MW



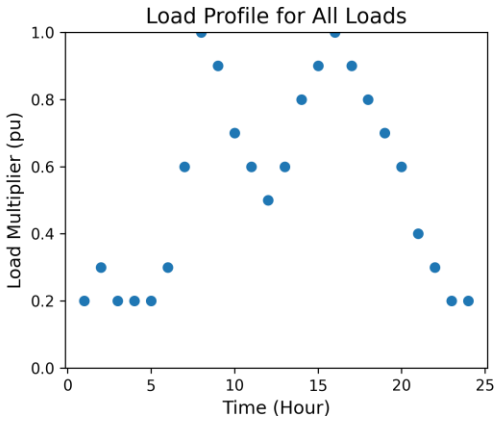
File: TimeBased\QSTS\overvoltage.py

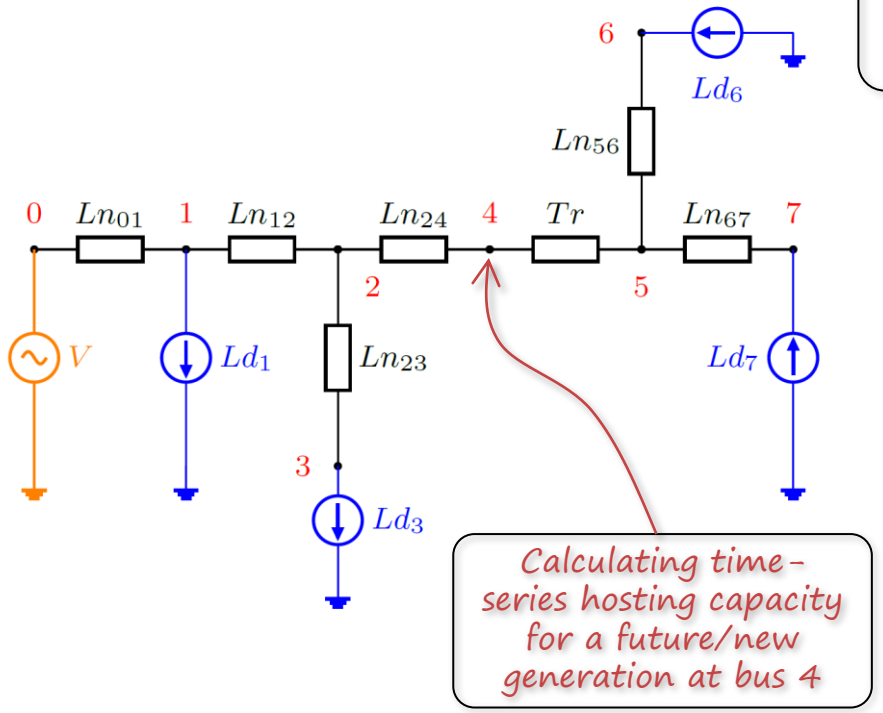
GM DA DT M/C IF **M**

Time-Series Hosting Capacity Example

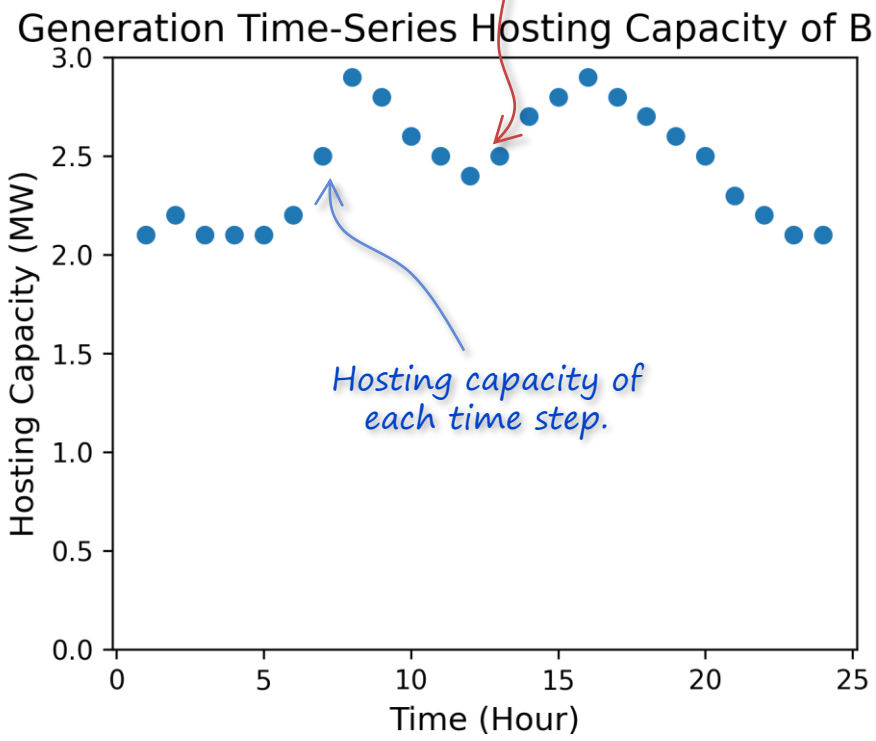
Metric:

- *Overvoltage*





The hosting capacity at hour 13 is 2.5 MW. It should be equal to or less than the result from the QSTS HC. In this case, they are the same because the generator in the QSTS HC has maximum output power at hour 13.

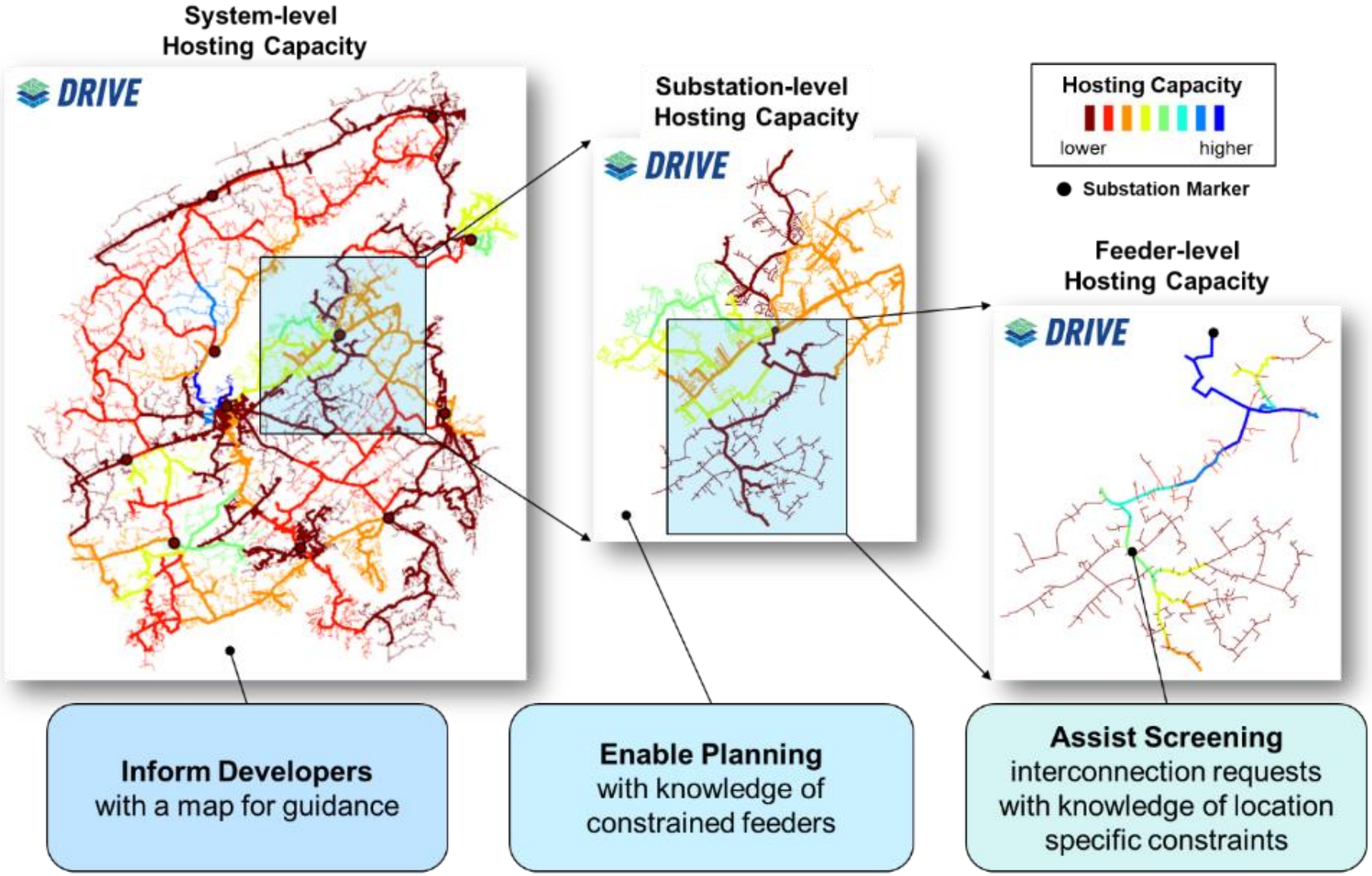


File: TimeBased\TSHC\overvoltage.py

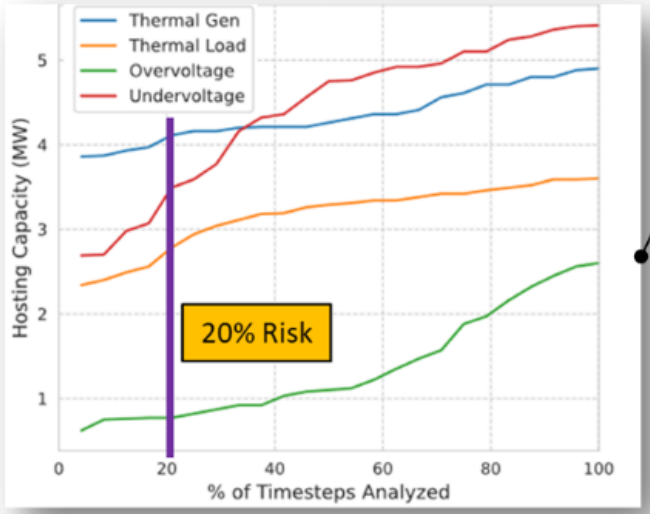
GM DA DT M/C IF **M**

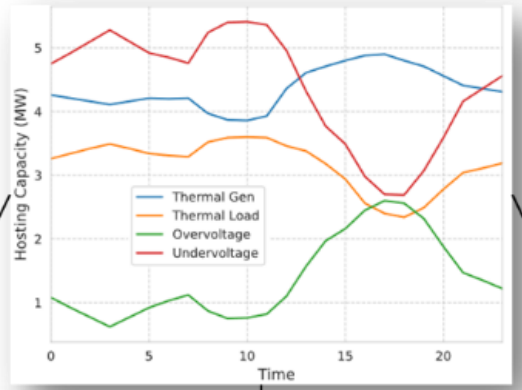
Applications

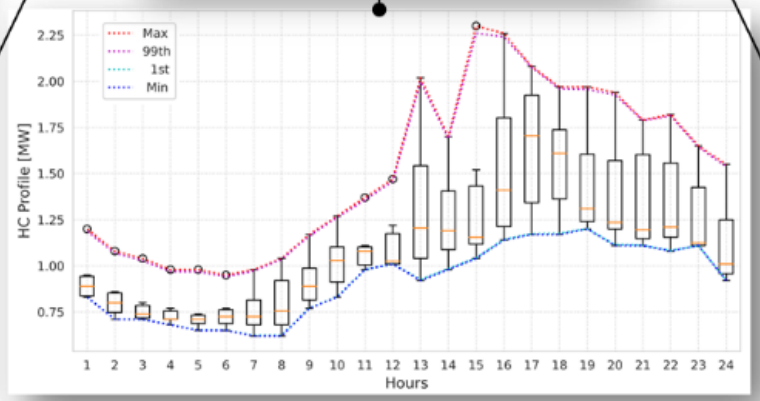
Applications | Worst-case Hosting Capacity

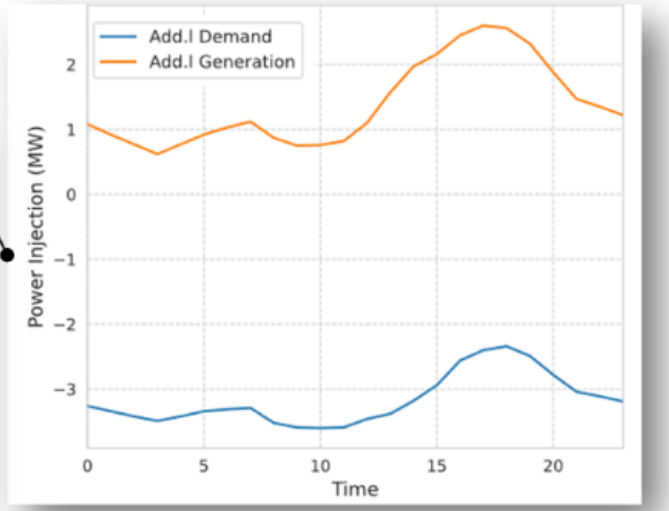


Applications | Time-series Hosting Capacity







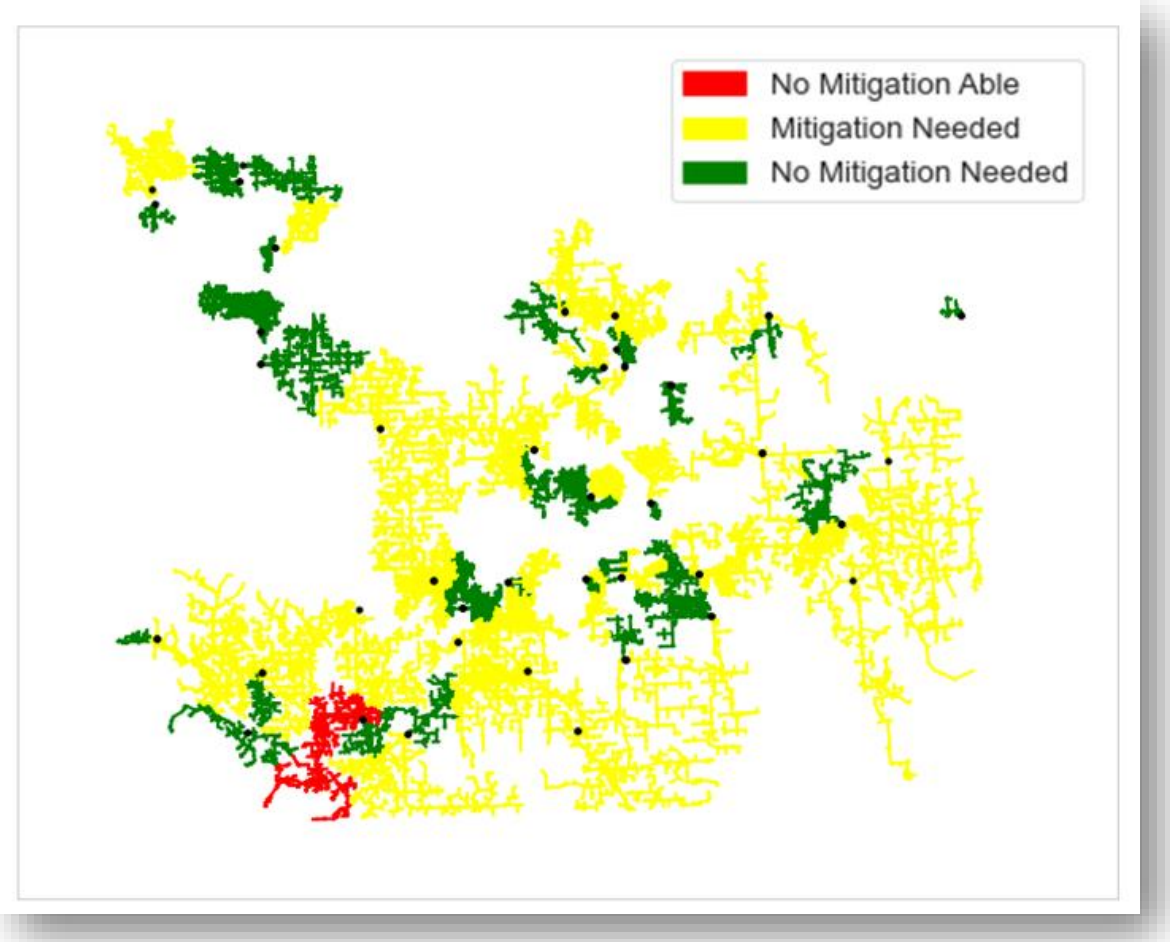


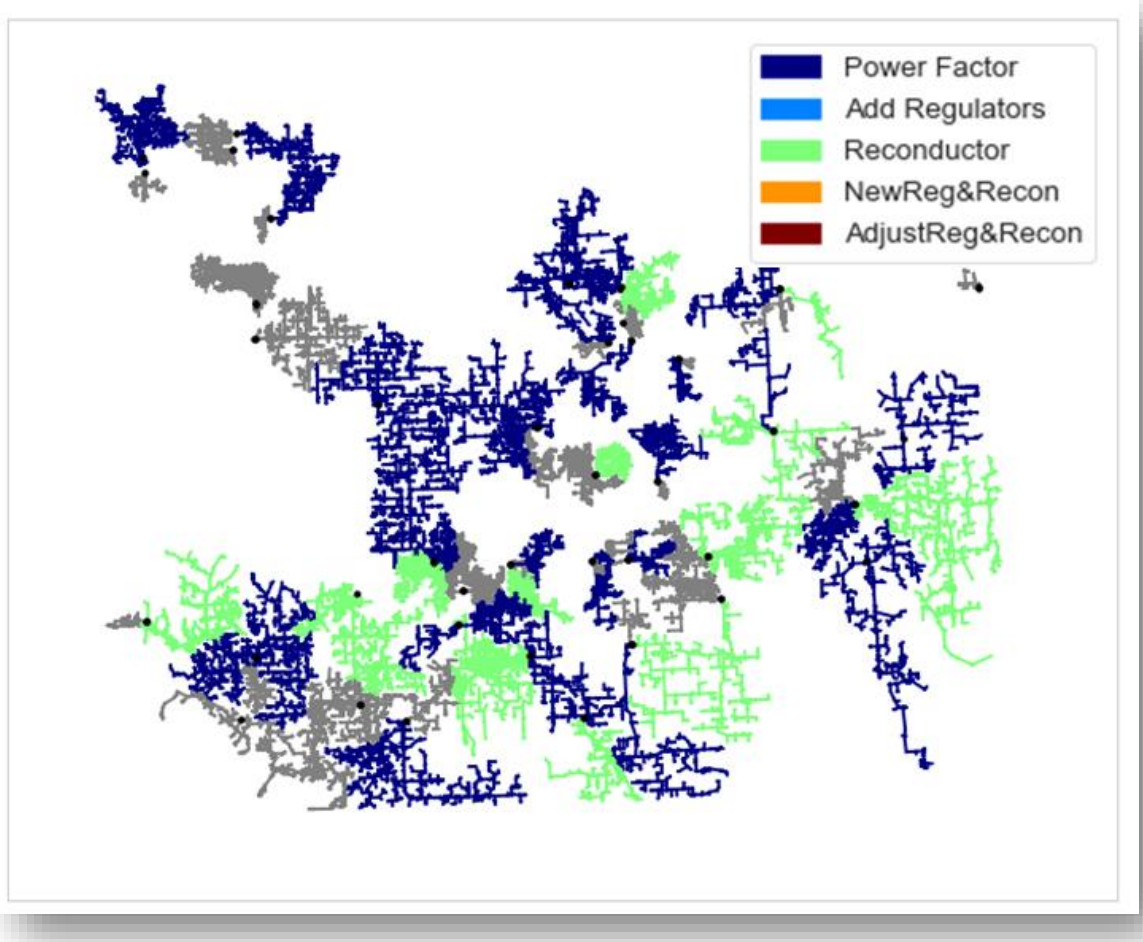
Risk-Based Planning
Planners can more appropriately understand how often the grid might be constrained delaying the requirement for grid upgrades

Management of Future Devices
Planners can develop managed use strategies that can defer grid upgrades while increasing the ability to accommodate new resources

Operational Constraints
Distribution operators can limit dispatchable devices if their desired dispatch exceeds the forecasted grid limits

Hosting Capacity – From Accommodation to Integration





Hosting capacity extended further to consider grid and customer solutions.

Final Thoughts…

- Hosting capacity is a process can be set up many ways
- Setting up the analysis requires knowing what matters most and what is needed to be answered
- Analytics are continually expanding to include more options and features

- **Reach out to EPRI to know more…**
  - **Matt Rylander, mrylander@epri.com**
  - **Paulo Radatz, pradatz@epri.com**