Mitigation Methods to Increase Feeder Hosting Capacity

Final Report | Report Number 19-45 | December 2019

NEW YORK
STATE OF
OPPORTUNITY.
NYSERDA

NYSERDA’s Promise to New Yorkers:

NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Mission Statement:

Advance innovative energy solutions in ways that improve New York’s economy and environment.

Vision Statement:

Serve as a catalyst – advancing energy innovation, technology, and investment; transforming New York’s economy; and empowering people to choose clean and efficient energy as part of their everyday lives.

Mitigation Methods to Increase Feeder Hosting Capacity

Final Report

Prepared for:

New York State Energy Research and Development Authority

Albany, NY

Sumit Bose
Senior Project Manager

Prepared by:

Electronic Power Research Institute

Palo Alto, CA

M. Rylander, L. Rogers, J. Deboever, P. Radatz,
Principle Investigators

Report 19-45 NYSERDA Contract 111071 December 2019

Notice

This report was prepared by Electronic Power Research Institute in the course of performing work contracted for and sponsored by the New York State Energy Research and Development Authority (hereafter “NYSERDA”). The opinions expressed in this report do not necessarily reflect those of NYSERDA or the State of New York, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it. Further, NYSERDA, the State of New York, and the contractor make no warranties or representations, expressed or implied, as to the fitness for particular purpose or merchantability of any product, apparatus, or service, or the usefulness, completeness, or accuracy of any processes, methods, or other information contained, described, disclosed, or referred to in this report. NYSERDA, the State of New York, and the contractor make no representation that the use of any product, apparatus, process, method, or other information will not infringe privately owned rights and will assume no liability for any loss, injury, or damage resulting from, or occurring in connection with, the use of information contained, described, disclosed, or referred to in this report.

NYSERDA makes every effort to provide accurate information about copyright owners and related matters in the reports we publish. Contractors are responsible for determining and satisfying copyright or other use restrictions regarding the content of reports that they write, in compliance with NYSERDA’s policies and federal law. If you are the copyright owner and believe a NYSERDA report has not properly attributed your work to you or has used it without permission, please email print@nyserda.ny.gov

Information contained in this document, such as web page addresses, are current at the time of publication.

Preferred Citation

New York State Energy Research and Development Authority (NYSERDA). 2019. “Mitigation Methods to Increase Feeder Hosting Capacity,” NYSERDA Report Number 19-45. Prepared by Electric Power Research Institute (EPRI), Palo Alto, CA. nyserda.ny.gov/publications

Abstract

Utilities performing supplemental reviews as interconnection requests for distributed energy resources (DER) typically focus on the system as it stands. This process is similar to hosting capacity studies that focus on the ability of the distribution grid to accommodate DER without system changes or infrastructure upgrades. When these studies find technical limitations that hinder the accommodation of DER, mitigation options can sometimes be identified. Unfortunately, technical analysis comes too late in the process and adequate time is often not available to verify those options as effective solutions. To allow for the technical analysis and verification of effective solutions early in the interconnection process, automated methods need to be developed.

In this report, processes are developed to automate the analysis of mitigation options to integrate higher levels of DER. Mitigation options include both grid-side solutions as well as customer-side solutions. These processes are developed to interface with OpenDSS and leverage knowledge of hosting capacity.

Keywords

Distributed Energy Resource, Distribution System Modeling, Hosting Capacity, Integration, Mitigation

Acknowledgments

The Electric Power Research Institute (EPRI), prepared this report.

Principal Investigators:
M. Rylander
L. Rogers
J. Deboever
P. Radatz

EPRI would like to acknowledge the efforts of The University of Melbourne Department of Electrical and Electronic Engineering.

Principal Investigators:
Andreas T. Procopiou
Luis (Nando) Ochoa

EPRI would also like to acknowledge the support of the New York State Energy Research and Development Authority (NYSERDA).

Table of Contents

List of Figures

List of Tables

Executive Summary

The key question addressed in this report concerns how mitigation options can be effectively and efficiently analyzed to find solutions for integrating distributed energy resources when interconnection requests exceed the distribution system's hosting capacity. The research examines traditional wires and non-wires mitigation options to help integrate higher levels of distributed energy resources. Wires options include utility-side upgrades such as voltage regulation and conductor replacement, while non-wires options include customer-side changes in operation of the resources. Processes are developed to examine the mitigation options and to efficiently find effective solutions.

Key findings involved (1) an analysis of customer and distribution grid mitigation as a way to understand the options for integrating higher levels of distributed energy resources, (2) processes are developed and validated to examine the mitigation options, and (3) examples are provided that implement the processes and find effective solutions based on cost and improvement to hosting capacity.

Interconnection requests of distributed energy resources can exceed the distribution system's hosting capacity. When this occurs, detailed technical analysis to provide solutions is commonly required but outside the scope and time of the initial and supplemental review process. The mitigation analysis discussed within this report could expedite a portion of that technical analysis and provide additional information to engineers during the review process.

1 Introduction

The penetration of distributed energy resources (DER) such as solar photovoltaic (PV) systems in the electric distribution grid can lead to technical issues such as voltage violations and thermal overloads of costly network assets (i.e., transformers, conductors). As these issues can limit the ability to accommodate high PV penetration, developers and regulators are asking electric distribution utilities about the required upgrades to proceed with interconnection.

Interconnection planning engineers are sometimes tasked to identify simple solutions to the technical issues during the supplemental review process.[1] For the utilities and in particular planning engineers to make more informed decisions early in the review process, advanced and practical distribution planning tools are required so that a suite of wires and technology-based mitigation options can be analyzed effectively and efficiently.

To meet this need, automated mitigation analyses are in the process of being developed to examine the suite of mitigation options. These analyses consider customer and grid-side options such as adjustments of voltage control, reconductoring, and smart inverter capabilities.

These options, as well as others, have been considered to integrate higher levels of PV generation beyond current hosting capacity through detailed analysis,[2] leveraging capabilities of OpenDSS (distribution system simulator).[3] New algorithms have also been developed and demonstrated using the Electric Power Research Institute (EPRI) DRIVE™ tool which will enable hosting capacity studies to determine not only how much generation can be accommodated at a specific location without any adverse impacts and without requiring upgrades,[4] but also how much generation can be integrated at that same location after alleviating the adverse impacts through grid and/or customer mitigation.

Hosting capacity with the additional layer to consider mitigation options increases the overall complexity of an already complex process. Predefined implementation of mitigation options is applied and automated in conjunction with the EPRI DRIVE™ tool to reassess the centralized (location specific) hosting capacity at a selected location. The selected feeder/location and mitigation option variables are user adjustable. Basic cost information can also be provided so that the change in hosting capacity due to the mitigation option can be compared with the cost to implement.

The mitigation assessment, however, is not based on an optimization. Therefore, the change in hosting capacity due to the implementation of mitigation is directly analyzed. Further tailoring the mitigation option variables and the implementation of the options might produce different results.

The goal of this analysis is to get a quick, simulation-based, idea of solutions that would increase the size of PV integration rather than performing a detailed assessment[5,6] that could provide the most optimal mitigation to maximize the size of the device integrated. For this reason, the advanced analytics contained in the mitigation module, described in this document, leverages the DRIVE platform.

This report summarizes the (1) suite of wires and technology-based mitigation options to be considered, (2) validation of the integration, and (3) application of the methodology on New York State distribution feeders. Mitigation option settings and costs will differ between utilities, so the examples in this document are purely for illustration.

2 Mitigation Options for DER Integration

A total of six mitigation options are currently examined in this mitigation analysis, which includes three customer-side and three grid-side options. The customer-side options include power factor, volt-var, and volt-watt control. The grid-side options include reconductoring, adjusting existing regulators, and adding new regulators. Future activities could expand the options available and/or analyze combinations of those options.

As previously discussed, the implementation of the options for mitigation is predefined. The following sections describe the execution in the current version of DRIVE to enable demonstration in New York State. Through user feedback, the methodology can evolve as necessary.

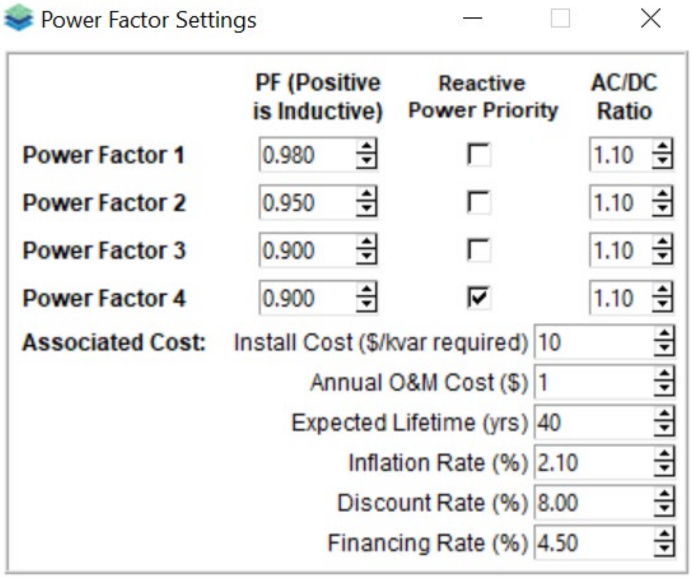
2.1 Power Factor

This mitigation option adjusts the reactive power output of future DER at the location selected. The user adjustable variables are shown in Figure 1. A total of four independent conditions are analyzed under the power factor option.

The inputs include the power factor of the DER, reactive power priority, and the AC/DC ratio. By enabling the reactive power priority option, active power output may be curtailed if sufficient capacity in the device to meet the desired power factor is not available. The capacity is influenced by the AC/DC ratio or alternatively the kilovolt-amps (kVA)/kilowatts (kW) rating.

In addition to the power flow variables, the inputs also include several economic variables that are applicable to all conditions analyzed. The associated cost is relative to what the utility would incur to integrate the device and is in terms of dollars per reactive power required. This cost might be based on the requirement to install capacitors of an equivalent size to source the reactive power. Other economic variables include the expected lifetime before a replacement is needed, annual operation and maintenance expense associated with the mitigation measure, inflation rate (annual escalation rate used to estimate replacement costs once the mitigation measure reaches its expected lifetime), discount rate (customer or organizational discount rate used for discounted cash flow analysis), and financing rate (average rate to finance capital expenditures which could be the interest rate for debt financed entities or the weighted average cost of capital).

Figure 1. Power Factor Option—User Adjustable Variables



Power Factor Settings

	PF (Positive is Inductive)	Reactive Power Priority	AC/DC Ratio
Power Factor 1	0.980	☐	1.10
Power Factor 2	0.950	☐	1.10
Power Factor 3	0.900	☐	1.10
Power Factor 4	0.900	☑	1.10

Associated Cost:

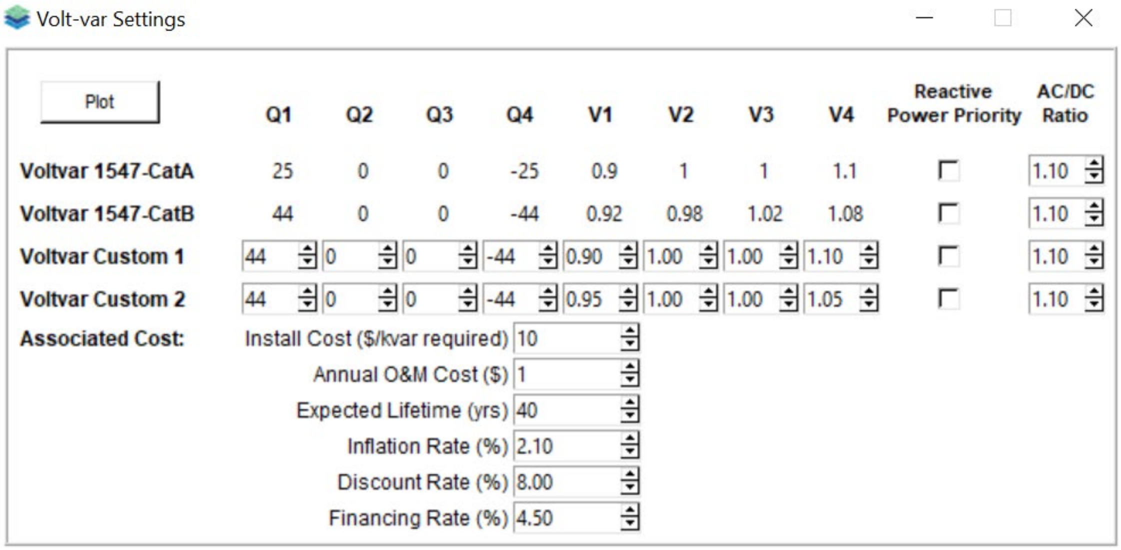
Install Cost ($/kvar required)	10
Annual O&M Cost ($)	1
Expected Lifetime (yrs)	40
Inflation Rate (%)	2.10
Discount Rate (%)	8.00
Financing Rate (%)	4.50

2.2 Volt-Var Control

This mitigation option adjusts the reactive power output of the device at the location selected. The user adjustable variables are shown in Figure 2. A total of four independent conditions are analyzed under the volt-var control option. Two of the conditions are based on the IEEE-1547 standard recommended settings, while two are adjustable.

The voltage/reactive power settings for each condition can be interpreted by the illustration in the figure. Economic variables and associated cost are the same as that defined for the power factor.

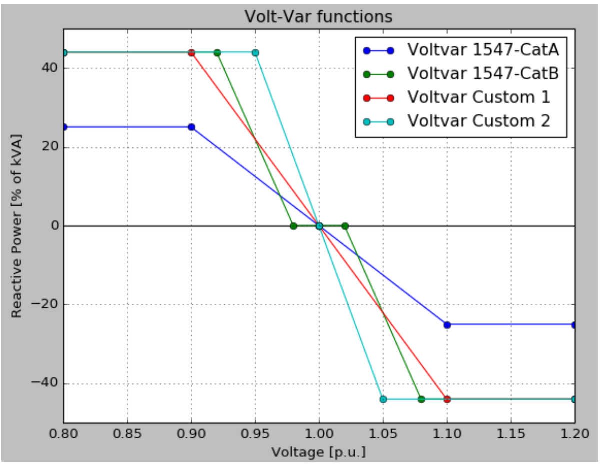
Figure 2. Volt-Var Control Option (a) User Adjustable Variables (b) Example Curves



	Q1	Q2	Q3	Q4	V1	V2	V3	V4	Reactive Power Priority	AC/DC Ratio
Voltvar 1547-CatA	25	0	0	-25	0.9	1	1	1.1	☐	1.10
Voltvar 1547-CatB	44	0	0	-44	0.92	0.98	1.02	1.08	☐	1.10
Voltvar Custom 1	44	0	0	-44	0.90	1.00	1.00	1.10	☐	1.10
Voltvar Custom 2	44	0	0	-44	0.95	1.00	1.00	1.05	☐	1.10

Associated Cost:
Install Cost ($/kvar required) 10
Annual O&M Cost ($) 1
Expected Lifetime (yrs) 40
Inflation Rate (%) 2.10
Discount Rate (%) 8.00
Financing Rate (%) 4.50

(a)



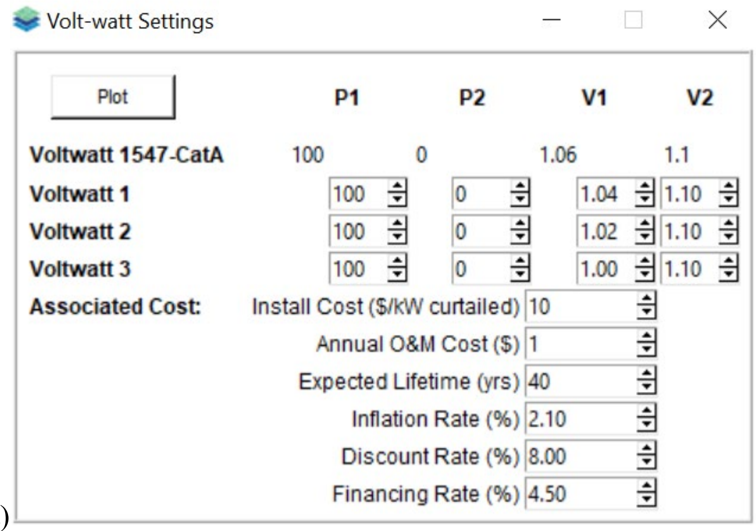
(b)

2.3 Volt-Watt Control

This mitigation option adjusts the active power output of the device at the location selected. The user adjustable variables are shown in Figure 3. A total of four independent conditions are analyzed under the volt-watt control option. One of the conditions is based on the IEEE-1547 standard recommended settings, while the other three are adjustable.

The voltage/active power settings for each condition can be interpreted by the illustration in the figure. The inputs for economic variables are the same as those previously defined, except the associated cost is based in terms of dollars per active power curtailed. This cost might be what the utility would incur to curtail the device.

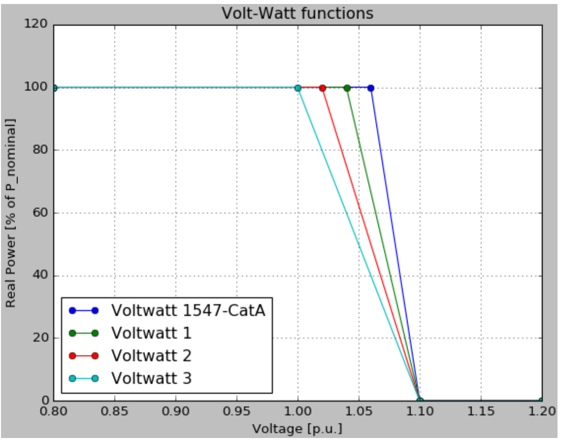
Figure 3. Volt-Watt Control Option (a) User Adjustable Variables (b) Example Curves



	P1	P2	V1	V2
Voltwatt 1547-CatA	100	0	1.06	1.1
Voltwatt 1	100	0	1.04	1.10
Voltwatt 2	100	0	1.02	1.10
Voltwatt 3	100	0	1.00	1.10

Associated Cost:
Install Cost ($/kW curtailed) 10
Annual O&M Cost ($) 1
Expected Lifetime (yrs) 40
Inflation Rate (%) 2.10
Discount Rate (%) 8.00
Financing Rate (%) 4.50

(a)



(b)

2.4 Adjust Regulators

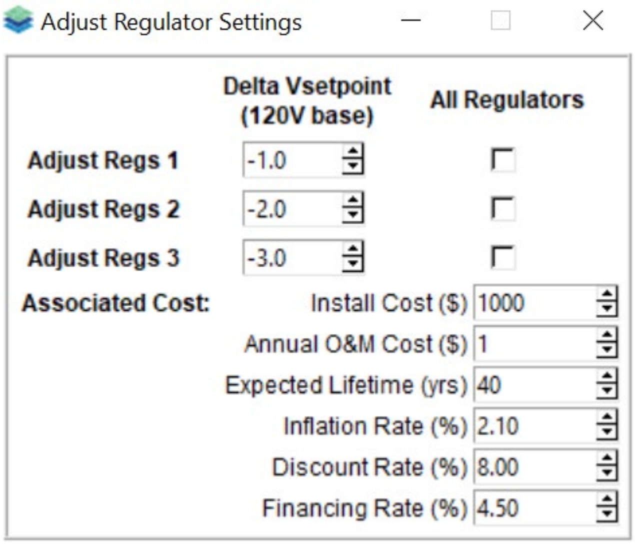
This mitigation option adjusts the set points of existing regulators on the feeder based on the selected location. The user adjustable variables are shown in Figure 4. A total of three independent conditions are analyzed under this option.

The primary variable that impacts the voltage profile of the feeder is the regulator voltage set point. A change to the voltage set point would uniformly shift the voltage across the regulation zone. If there are no regulators upstream from the selected location for analysis, no adjustments will be made. To shift the voltage set point of all regulation zones, the user would enable the option to adjust All Regulators. Note, a change in voltage set point will not change the demand of connected load on the feeder in the analysis.

The change in voltage profile, however, can potentially eliminate existing overvoltage violations on the feeder. At the same time, shifting the voltage profile down too far may cause undervoltage violations to occur, thus the user must be aware of creating an undesired impact which is made available by observing the undervoltage hosting capacity.

The inputs for economic variables are the same as those previously defined, except the associated cost is based in terms of dollars per regulator that gets adjusted. Again, this is a utility cost to integrate the device.

Figure 4. Adjust Regulators Option—User Adjustable Variables



Adjust Regulator Settings

	Delta Vsetpoint (120V base)	All Regulators
Adjust Regs 1	-1.0	☐
Adjust Regs 2	-2.0	☐
Adjust Regs 3	-3.0	☐

Associated Cost:

Install Cost ($) 1000
Annual O&M Cost ($) 1
Expected Lifetime (yrs) 40
Inflation Rate (%) 2.10
Discount Rate (%) 8.00
Financing Rate (%) 4.50

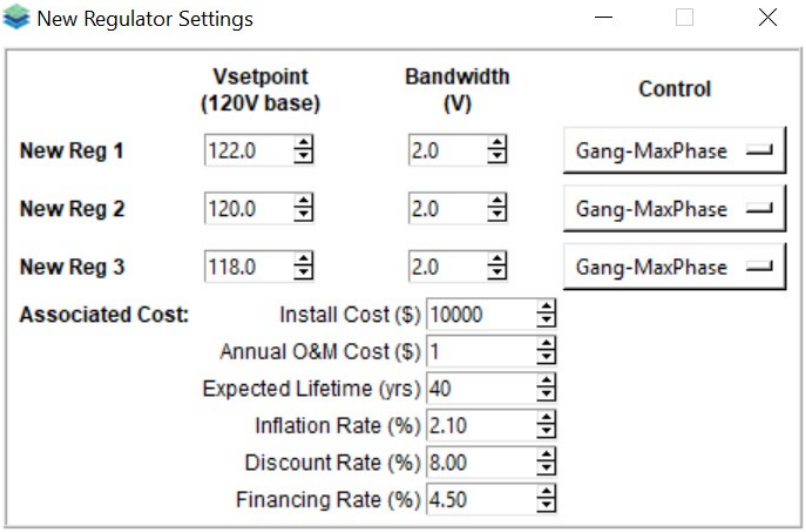
2.5 Add Regulators

This mitigation option adds a new regulator on the feeder based on the selected location. The user adjustable variables are shown in Figure 5. A total of three independent conditions are analyzed under this option.

The new regulator is placed halfway (based on number of buses) between the selected location and either an upstream regulator or the feeder head. The primary variable for the new regulator is the new voltage set point. This set point will adjust the voltage that occurs in the new regulation zone and other regulation zones will be unaffected. The controlled voltage bus of the new regulation zone will be exactly at the desired set point. The bandwidth variable only applies if the user has selected the option in the hosting capacity analysis to adjust regulated voltage buses to the edge of their bandwidth. The added regulator can also be gang controlled based on the maximum voltage at the bus or alternatively by the individual phase voltages. The ultimate change in voltage profile can potentially eliminate existing voltage violations; however, the user must remain aware that new violations may occur on the feeder.

The inputs for economic variables are the same as those previously defined, except the associated cost is based in terms of dollars for the new regulator that the utility would have to install.

Figure 5. Add Regulators Option—User Adjustable Variables



New Regulator Settings

	Vsetpoint (120V base)	Bandwidth (V)	Control
New Reg 1	122.0	2.0	Gang-MaxPhase
New Reg 2	120.0	2.0	Gang-MaxPhase
New Reg 3	118.0	2.0	Gang-MaxPhase

Associated Cost:

Install Cost ($)	10000
Annual O&M Cost ($)	1
Expected Lifetime (yrs)	40
Inflation Rate (%)	2.10
Discount Rate (%)	8.00
Financing Rate (%)	4.50

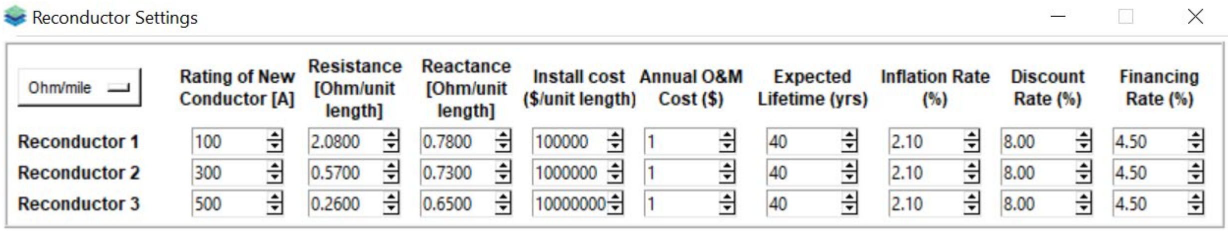
2.6 Reconductor

This mitigation option adjusts the rating and impedance of sections on the feeder upstream from the selected location. The user adjustable variables are shown in Figure 6. A total of three independent conditions are analyzed under this option.

The reconductor option replaces conductors upstream from the selected location based on the original rating of each section and the specified rating of the new conductor. Reconductoring only occurs if the existing conductor is rated lower than the desired new conductor. When this occurs, the rating and impedance of the original section is adjusted. A change of impedance will indirectly change the voltage profile due to connected load/generation. The magnitude of connected load/generation is not altered, but the voltage drop due to that load/generation is determined. The new voltage profile, impedances, and ratings after reconductoring are used for the mitigation option analysis. The ultimate change in voltage profile can potentially eliminate existing voltage violations; however, the user must remain aware that new violations may occur on the feeder.

The inputs for economic variables are the same as those previously defined, except the associated cost is based in terms of dollars per distance of new conductor the utility would have to install. The economic variables are also unique for each of the conditions being analyzed.

Figure 6. Reconductor Option—User Adjustable Variables



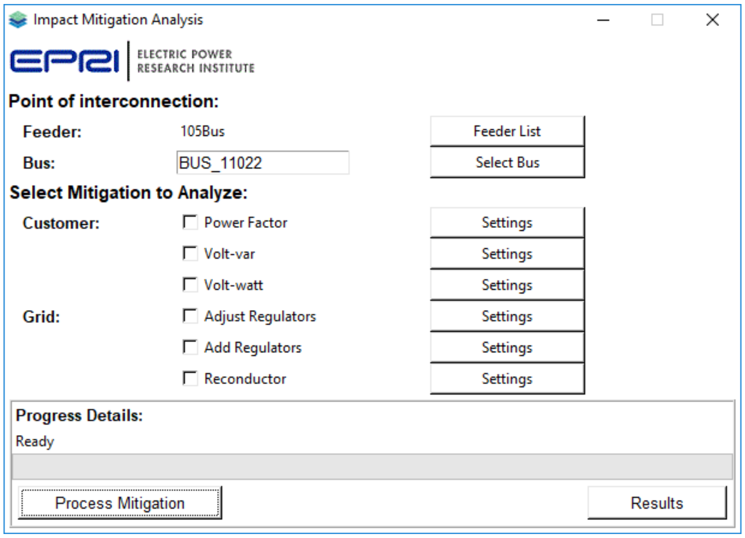
Ohm/mile	Rating of New Conductor [A]	Resistance [Ohm/unit length]	Reactance [Ohm/unit length]	Install cost ($/unit length)	Annual O&M Cost ($)	Expected Lifetime (yrs)	Inflation Rate (%)	Discount Rate (%)	Financing Rate (%)
Reconductor 1	100	2.0800	0.7800	100000	1	40	2.10	8.00	4.50
Reconductor 2	300	0.5700	0.7300	1000000	1	40	2.10	8.00	4.50
Reconductor 3	500	0.2600	0.6500	10000000	1	40	2.10	8.00	4.50

2.7 Running the Analysis

The mitigation analysis is conducted in the DRIVE platform. This makes the analysis compatible with multiple software tools for distribution system vendors.[7] The mitigation analysis utilizes the same four files that contain feeder information extracted from the original feeder model.[8] Using the same feeder data that DRIVE uses to conduct a hosting capacity study enables direct comparison of the original hosting capacity to the hosting capacity after application of each mitigation option.

When conducting a mitigation analysis, the user selects (1) a feeder, (2) the specific location/bus on that feeder to reassess hosting capacity after applying each mitigation option, and (3) the specific mitigation options to consider as shown in Figure 7.

Figure 7. Mitigation Analysis Setup



Point of interconnection:

Feeder: 105Bus

Bus: BUS_11022

Select Mitigation to Analyze:

Customer:
- ☐ Power Factor
- ☐ Volt-var
- ☐ Volt-watt

Grid:
- ☐ Adjust Regulators
- ☐ Add Regulators
- ☐ Reconductor

Progress Details:
Ready

3 Validation

This section presents the evaluation and performance of the developed DRIVE mitigation analysis summarized in section 2. The performance is evaluated against various detailed assessments[9] considering multiple bus locations and feeders. Validation on a subset of those conditions is presented here.

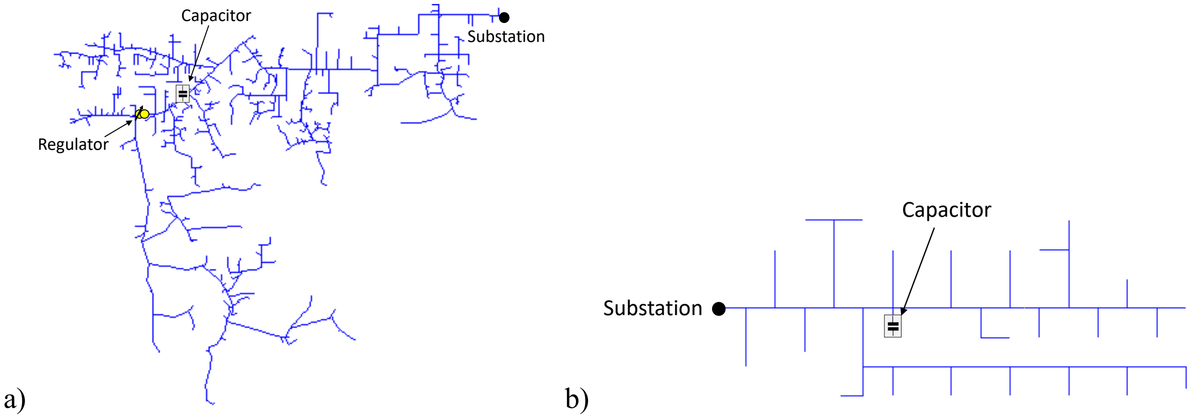
3.1 Performance Assessment

One synthetic and one real distribution feeder are used for the performance assessments. The basic characteristics of the feeders used in this report and their topologies are given in Table 1 and Figure 8, respectively.

Table 1. Feeders: Basic Characteristics

Feeder Name	Substation	# of Regulators	# of Capacitors	# of Lines	# of Loads	Peak demand
683 (real)	69/12kV 28MVA	2	1	2892	1140	5.9MVA
105 (Synthetic)	Vsource 12.47kV	1	1	103	51	6.4MVA

Figure 8. Feeders: (a) Feeder 683 (b) Feeder 105



The hosting capacity metrics considered in this validation include overvoltage, voltage deviation, and thermal impacts. Because some mitigation options can cause undesired impacts such as undervoltages to occur, an undervoltage metric must also be examined as part of the analysis.

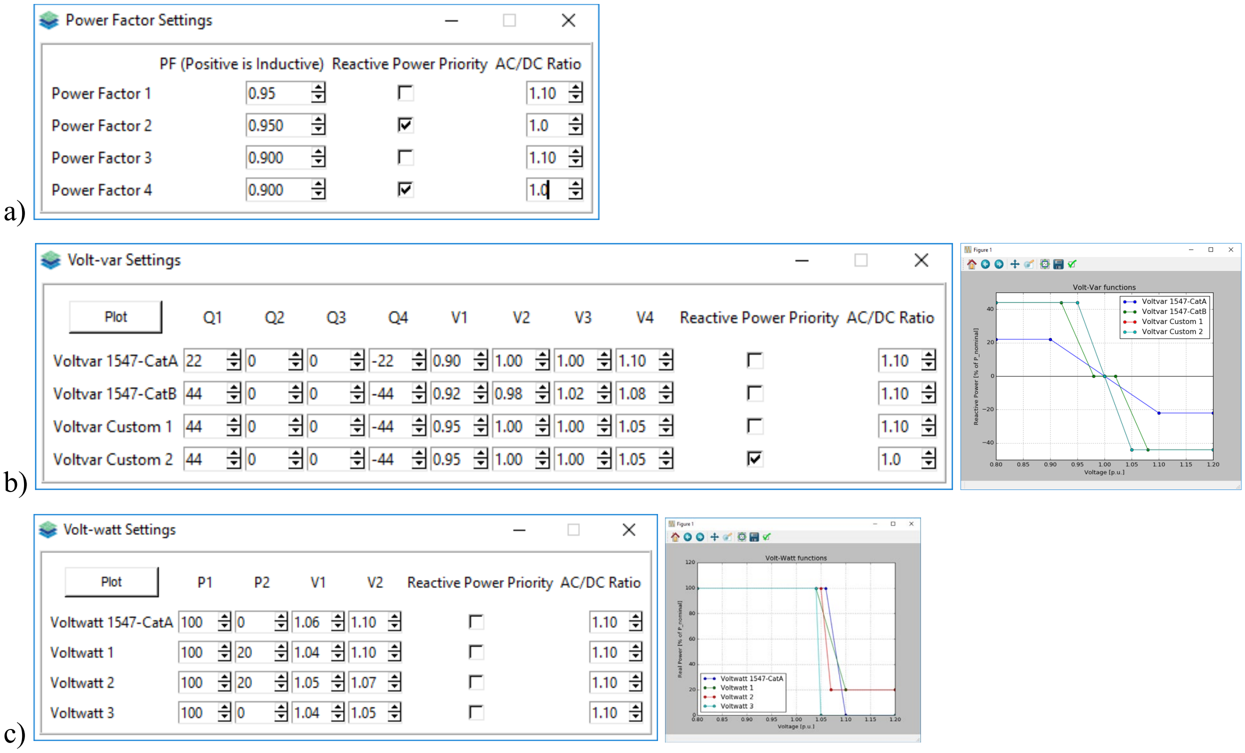
Three methods, applied to examine the results of the DRIVE mitigation analysis, and brief descriptions are as follows. Validation from a subset of analyses for all three methods are included in this report.

1. Place a DER with size equal to the reported hosting capacity into the original DSS model with the mitigation to examine if the expected violation occurs.
2. Compare the DRIVE mitigation analysis hosting capacity to the DRIVE analysis hosting capacity conducted on a feeder with the mitigation already applied.
3. Compare the DRIVE mitigation analysis hosting to a detailed hosting capacity analysis that considers mitigation.

3.2 Comparison Method 1

In this first performance assessment, the DRIVE mitigation analysis is conducted on a mid-feeder location on Feeder 683. Figure 9 illustrates the settings for each of the customer-side mitigation options. The resulting hosting capacities are shown in Table 2.

Figure 9. Mitigation Options (a) Power Factor (b) Volt-Var (c) Volt-Watt



a)

	PF (Positive is Inductive)	Reactive Power Priority	AC/DC Ratio
Power Factor 1	0.95	☐	1.10
Power Factor 2	0.950	☑	1.0
Power Factor 3	0.900	☐	1.10
Power Factor 4	0.900	☑	1.0

b)

	Q1	Q2	Q3	Q4	V1	V2	V3	V4	Reactive Power Priority	AC/DC Ratio
Voltvar 1547-CatA	22	0	0	-22	0.90	1.00	1.00	1.10	☐	1.10
Voltvar 1547-CatB	44	0	0	-44	0.92	0.98	1.02	1.08	☐	1.10
Voltvar Custom 1	44	0	0	-44	0.95	1.00	1.00	1.05	☐	1.10
Voltvar Custom 2	44	0	0	-44	0.95	1.00	1.00	1.05	☑	1.0

c)

	P1	P2	V1	V2	Reactive Power Priority	AC/DC Ratio
Voltwatt 1547-CatA	100	0	1.06	1.10	☐	1.10
Voltwatt 1	100	20	1.04	1.10	☐	1.10
Voltwatt 2	100	20	1.05	1.07	☐	1.10
Voltwatt 3	100	0	1.04	1.05	☐	1.10

Table 2. Feeder 683 Mid-Feeder Bus Hosting Capacity Results for Customer-Side Mitigation

Mitigation	OverVoltage	VoltageDeviation	UnderVoltage	Thermal
Power Factor 1	2	1.1	6.9	2.3
Power Factor 2	2.1	1.1	7.3	2.5
Power Factor 3	2.8	1.4	5.3	2.2
Power Factor 4	3.5	1.7	5.6	2.4
Voltvar 1547-CatA	1.4	0.7	8.3	2.5
Voltvar 1547-CatB	1.7	0.7	5.7	2.3
Voltvar Custom 1	3.1	0.9	5.1	2.2
Voltvar Custom 2	3.6	0.9	5.6	2.4
Voltwatt 1547-CatA	1.2	0.7	10	10
Voltwatt 1	1.4	0.7	10	10
Voltwatt 2	1.2	0.7	10	10
Voltwatt 3	10	0.7	10	10

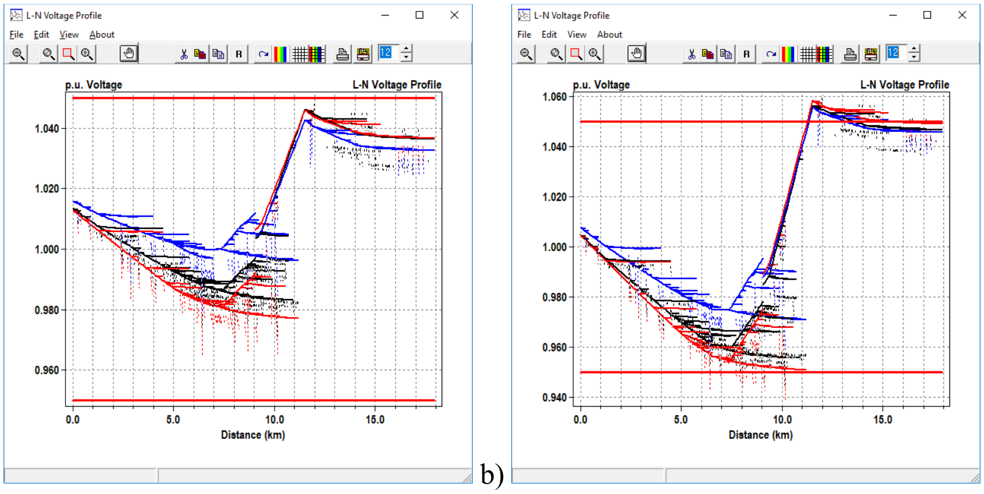
These hosting capacity values were then used to define the size of the DER added back into the original feeder model. The added DER also included the corresponding mitigation. Table 3 illustrates the impact in the original DSS model after various PV system sizes with the power factor 4 settings were added. The various system sizes are based on each of the metrics that are being validated. The highlighted values are of interest for the specific metric.

The allowable impact that was used to define hosting capacity in the mitigation assessment was 1.05 Voltage power unit (Vpu) for overvoltage, 0.03 Vpu for voltage deviation, 100% for thermal, and 0.95 Vpu of undervoltage. As can be seen, the impact is near the threshold for each metric. Further illustration of the validation can be seen in Figure 10 where the DER size is based on the overvoltage and undervoltage metrics.

Table 3. Power Factor 4 Hosting Capacity Validation

Metric	PV size (MW)	Max V (pu)	Max Vdev (pu)	Max Loading (%)	Min V (pu)
Overvoltage	3.5	1.0479	0.05272	147	0.97711
Voltage Deviation	1.7	1.0275	0.03113	75	0.99221
Thermal	2.4	1.0366	0.0408	98	0.98715
Undervoltage	5.6	1.0594	0.06512	241	0.95083

Figure 10. Power Factor 4 Result Validation (a) 3.5 MW Added (b) 5.6 MW Added



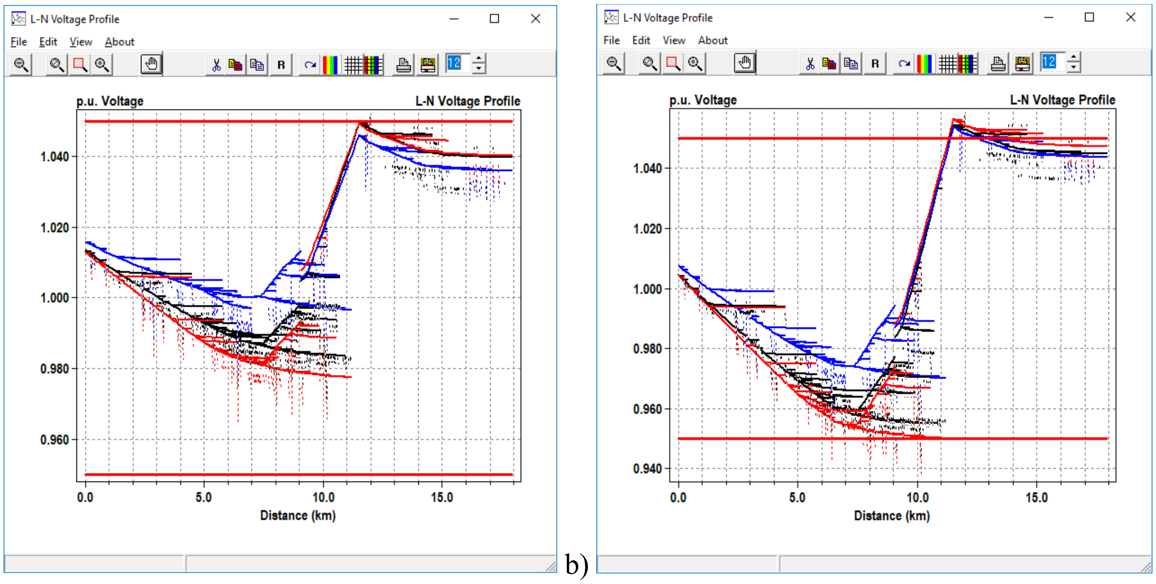
a) b)

Table 4 illustrates the impact in the original DSS model after various PV system sizes with the volt-var custom 2 settings are added. The impact from the mitigation is not linear, which is attributed to the complexity of a distribution feeder analysis. Figure 11 shows that both 3.6 megawatts (MW) and 5.6 MW of DER barely cause an overvoltage, however, 5.6 MW is required to cause an undervoltage on the feeder. The majority of this non-linear impact is captured in the DRIVE mitigation analysis but can also lead to some mismatch in results. Overall, the mitigation-based hosting capacity from DRIVE causes a violation for each metric in the DSS model.

Table 4. Volt-Var Custom 2 Hosting Capacity Validation

Metric	PV size (MW)	Max V (pu)	Max Vdev (pu)	Max Loading (%)	Min V (pu)
Overvoltage	3.6	1.0512	0.05612	151	0.97757
Voltage Deviation	0.9	1.0277	0.03047	76	1.0036
Thermal	2.4	1.0454	0.04972	95	0.99229
Undervoltage	5.6	1.0575	0.06322	240	0.95013

Figure 11. Volt-Var Custom 2 Result Validation (a) 3.6 MW Added (b) 5.6 MW Added



a) b)

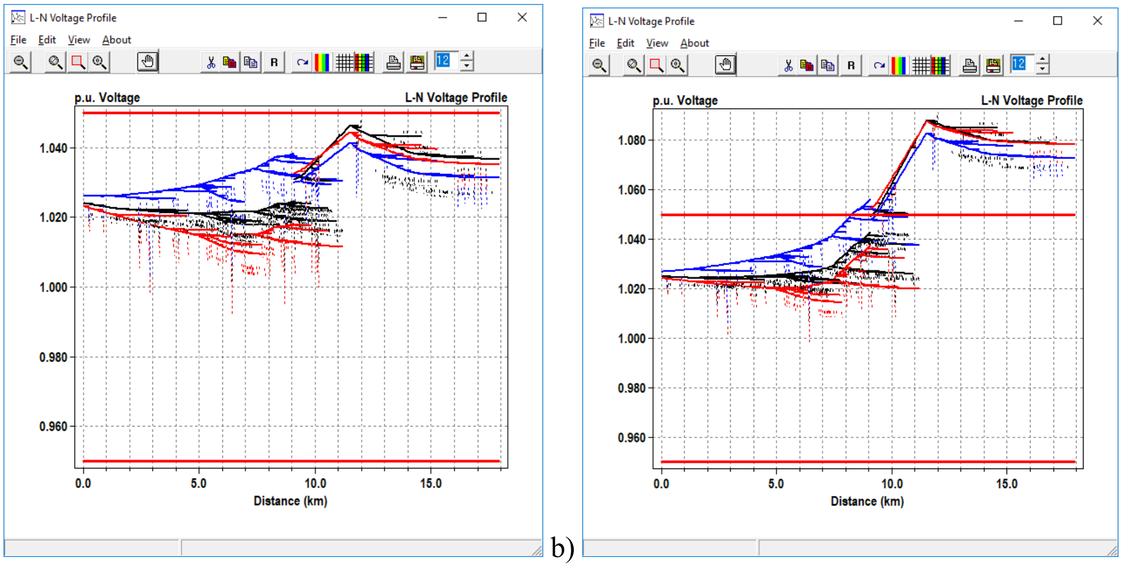
Table 5 illustrates the impact in the original DSS model after various PV system sizes with the Volt-Watt 1547-CatA settings are added. Volt-Watt 1547-CatA doesn't begin to curtail until voltage is already above the overvoltage threshold, so that the mitigation option doesn't improve hosting capacity. Similarly, the voltage deviation threshold is reached prior to the volt-watt control operating in this example. The thermal and undervoltage hosting capacities from the mitigation analysis are each 10 MW; however, the full 10 MW with volt-watt control would not solve in DSS. This illustrates a significant limitation for vendor tools where complex scenarios become difficult to solve. The advantage of implementing such an analysis in DRIVE is that the scenario is simplified leading to an easier solution. The highest penetration that could be solved in DSS examined 7 MW. Increasing penetration from 0.7 to 7.0 MW only increased loading by 11%, so thermal should not have been an issue with an additional 3 MW penetration. Similarly, undervoltage will not be an issue as illustrated in Figure 12.

Table 5. Volt-Watt 1547-CatA Hosting Capacity Validation

Metric	PV size (MW)	Max V (pu)	Max Vdev (pu)	Max Loading (%)	Min V (pu)
Overvoltage	1.2	1.0476	0.05122	77	1.0094
Voltage Deviation	0.7	1.0309	0.03073	76	1.0065
Thermal	7.0*	1.09	0.09437	87	1.0145
Undervoltage	7.0*	1.09	0.09437	87	1.0145

* 10 MW would not solve in DSS

Figure 12. Volt-Watt 1547-CatA Result Validation (a) 1.2 MW Added (b) 7.0 MW Added



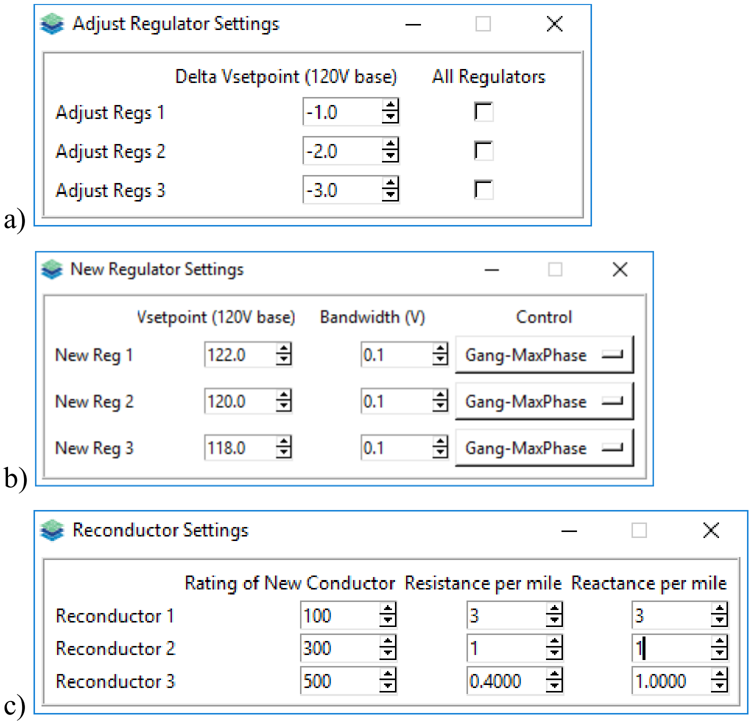
a) b)

3.3 Comparison Method 2

In the second performance assessment, the mid-feeder bus location on Feeder 683 was also examined, however, slightly different original feeder model conditions existed. Thus, hosting capacity values in this assessment should not be compared to the previous assessment.

Similarly, to the first assessment, the mitigation hosting capacity analysis was first conducted in DRIVE. Figure 13 illustrates the settings used for each mitigation option analysis. Table 6 illustrates the resulting hosting capacity for each mitigation option.

Figure 13. Mitigation Options (a) Adjust Regulators (b) New Regulators (c) Reconductor



a) Adjust Regulator Settings

	Delta Vsetpoint (120V base)	All Regulators
Adjust Regs 1	-1.0	☐
Adjust Regs 2	-2.0	☐
Adjust Regs 3	-3.0	☐

b) New Regulator Settings

	Vsetpoint (120V base)	Bandwidth (V)	Control
New Reg 1	122.0	0.1	Gang-MaxPhase
New Reg 2	120.0	0.1	Gang-MaxPhase
New Reg 3	118.0	0.1	Gang-MaxPhase

c) Reconductor Settings

	Rating of New Conductor	Resistance per mile	Reactance per mile
Reconductor 1	100	3	3
Reconductor 2	300	1	1
Reconductor 3	500	0.4000	1.0000

Table 6. Feeder 683 Mid-Feeder Bus Hosting Capacity Results for Grid-Side Mitigation

Mitigation	OverVoltage	VoltageDeviation	UnderVoltage	Thermal
Adjust Regs 1	1.5	0.7	10	2.5
Adjust Regs 2	1.7	0.7	10	2.5
Adjust Regs 3	1.9	0.7	0	2.5
New Reg 1	0.9	0.7	10	2.5
New Reg 2	1.4	0.7	10	2.5
New Reg 3	1.7	0.7	0	2.5
Reconductor 1	1.3	0.7	10	2.5
Reconductor 2	1.9	1.1	10	6.6
Reconductor 3	3.6	2	10	10

The results from the mitigation assessments (change in regulator settings, location of new regulator, and specifics of reconductoring) were then added into the original feeder model. The new model was then reanalyzed in DRIVE using the standard hosting capacity analysis that does not consider mitigation. This procedure works for mitigation on the side of the grid because the mitigation actually changes the baseline model prior to the analysis in DRIVE. Options on the side of the customer cannot be analyzed this way because that mitigation is applied on the DER being analyzed during the hosting capacity loop.

Figure 14 compares the hosting capacity from the DRIVE mitigation analysis to the DRIVE standard analysis of the modified model with the changes for Adjust Regulators 1. The existing regulator on the feeder is slightly upstream from the analyzed location, thus decreasing the set point of that regulator by 1 volt slightly increases the overvoltage hosting capacity by 200 kW in both analyses. The other metrics are not impacted by the change in regulator set point, thus their hosting capacities remain the same for the mitigation analysis and the standard analysis.

Figure 14. Adjust Regulators 1 Result Validation

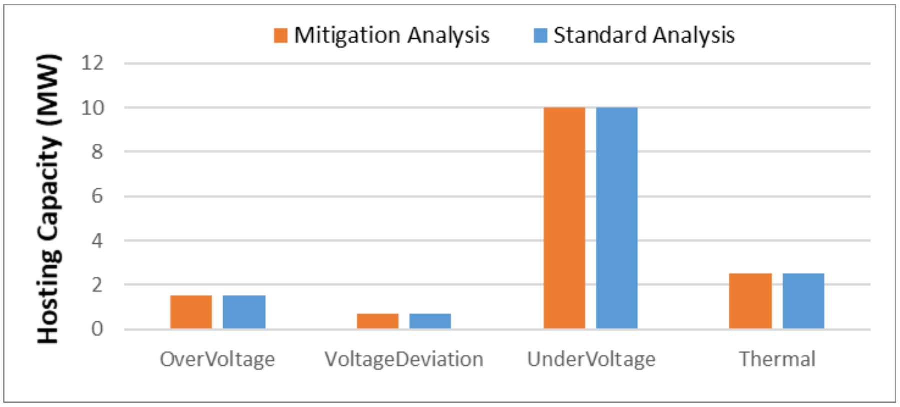


Figure 15 illustrates the impact from the New Regulators 3 mitigation option. Adding a new regulator with a slightly lower set point than the current voltage profile slightly increases the overvoltage hosting capacity in both solutions. The lower set point, however, decreases voltage beyond the undervoltage threshold, thus the undervoltage hosting capacity for this mitigation option becomes zero. Effectively, this is not a viable option. Voltage deviation and thermal metrics are unchanged.

Figure 15. New Regulators: Three-Result Validation

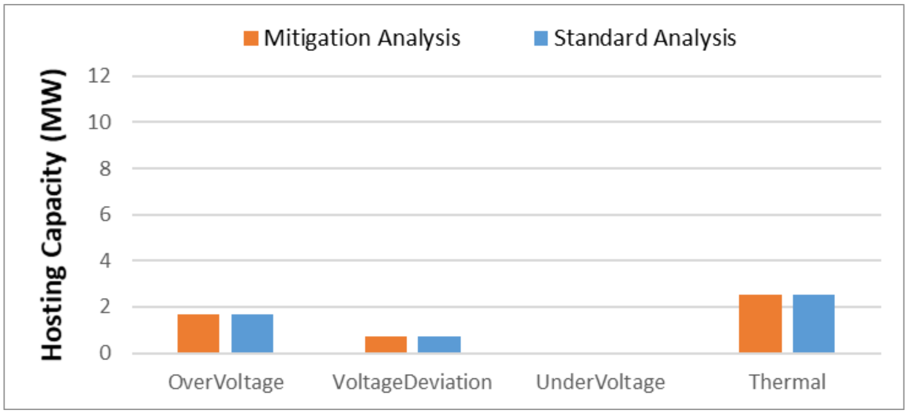
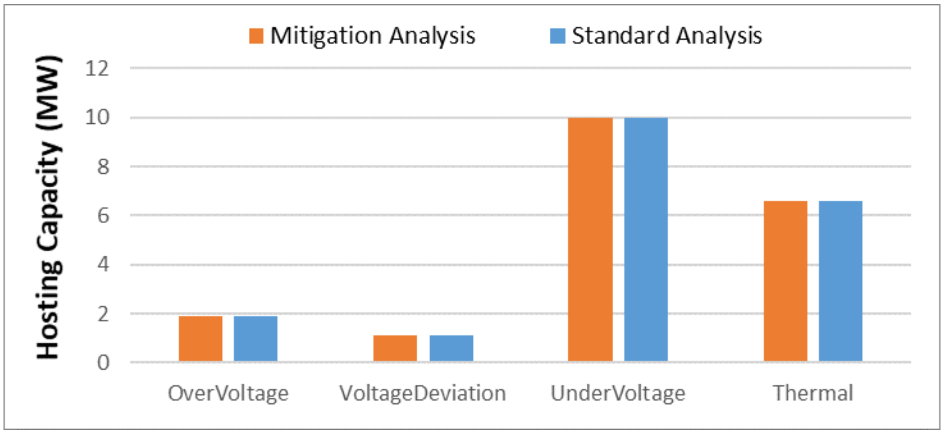


Figure 16 illustrates the impact from the Reconductor 2 mitigation option. Results from both analyses are identical. The new conductor is rated higher and has less impedance, thus overvoltage, voltage deviation, and thermal hosting capacities increase.

Figure 16. Reconductor 2 Result Validation



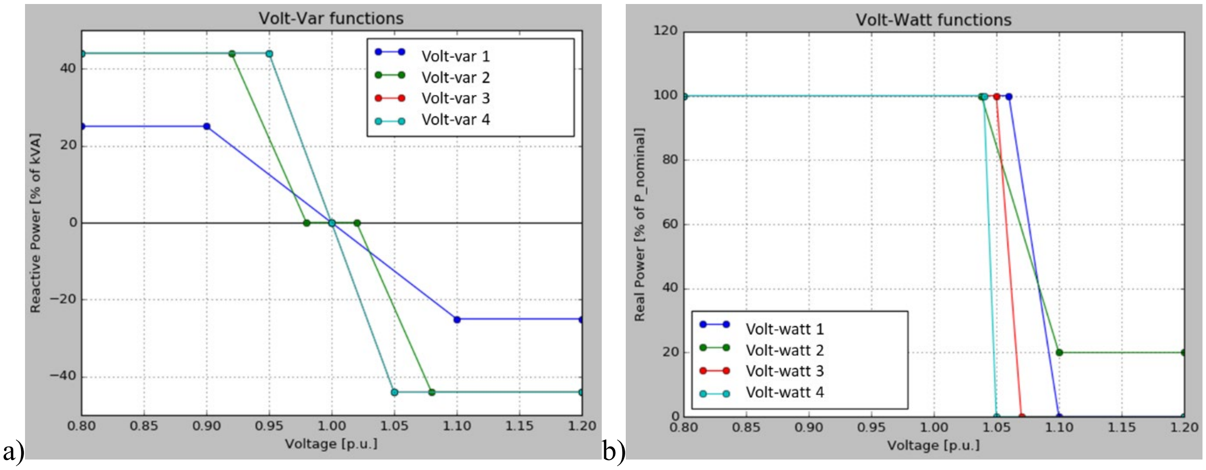
3.4 Comparison Method 3

The third performance assessment compares the DRIVE mitigation hosting capacity with a separate detailed hosting capacity studies on the same feeder. OpenDSS is used for the detailed study. The customer-side solutions and settings considered are given in the Table 7 and Figure 17.

Table 7. Suite of Solutions and Settings

Solution	Setting	Pwr Prty	Inv Size
Fixed PF 1	0.95	P	1.1
Fixed PF 2	0.95	Q	1.0
Fixed PF 3	0.90	P	1.1
Fixed PF 4	0.90	Q	1.0
Volt-Var 1	IEEE-Cat A	P	1.1
Volt-Var 2	IEEE-Cat B	P	1.1
Volt-Var 3	Custom Aggressive	P	1.1
Volt-Var 4	Custom Aggressive	Q	1.0
Volt-Watt 1	IEEE/CA/HA	P	1.1
Volt-Watt 2	Australia	P	1.1
Volt-Watt 3	Europe	P	1.1
Volt-Watt 4	Custom Aggressive	P	1.1

Figure 17. Inverter Settings (a) Volt-Var (b) Volt-Watt



a) b)

A middle and end bus are examined on Feeder 105 in this performance assessment. Due to the complexities of a detailed hosting capacity analysis involving mitigation options, only overvoltage and thermal metrics are considered. Figure 18 and Figure 19 present the comparison results of the two investigated buses on Feeder 105 at the middle and end locations, respectively.

In most cases, DRIVE is found to have a high accuracy when compared to results using OpenDSS. In the cases where results differ, the following reasons were identified:

- The difference “Fixed PF 2” and “Fixed PF 4” occurred because OpenDSS did not support reactive power priority with the standard power factor control function. In this case, OpenDSS limits the reactive power output, thus resulting in a lower hosting capacity. This functionality is currently being added to OpenDSS, but it raises awareness to the fact that tools are evolving and may have a limited set of options for comparable analysis.
- The voltage reference used by the DRIVE control algorithm is not the same as the one used by OpenDSS, creating differences to the underlying control methodology of volt-var and volt-watt. For example, DRIVE volt-watt and volt-var functions are designed to use the maximum voltage of the individual phases at the monitored location whereas OpenDSS uses the average voltage of the individual phases. Given that the DRIVE functions will use a higher voltage than the one used by the detailed analysis, the corresponding active power curtailment (due to volt-watt) or reactive power absorption (due to volt-var) is expected to be higher.
    - Furthermore, the volt-watt 4 setting curtails power to zero at 1.05 Vpu, which is the same as the overvoltage hosting capacity threshold. Using the maximum voltage as the control parameter implies that if any phase gets to 1.05 Vpu, the PV is effectively curtailed to zero and the PV will not cause a violation. For this reason, DRIVE shows a 10 MW hosting capacity. However, using the average phase voltage on an unbalanced system implies that there will always be one phase above 1.05 Vpu before the average phase voltage reaches 1.05 Vpu, thus a hosting capacity below 10 MW can occur.

- Differences due to OpenDSS convergence issues: the OpenDSS power flow analysis would not converge for penetration levels above 5.2 MW at the end-point location using volt-watt control, and thus the actual hosting capacity using the detailed method could not be determined.

Figure 18. Feeder 105 Mid-Feeder Bus Results (a) Overvoltage and (b) Thermal

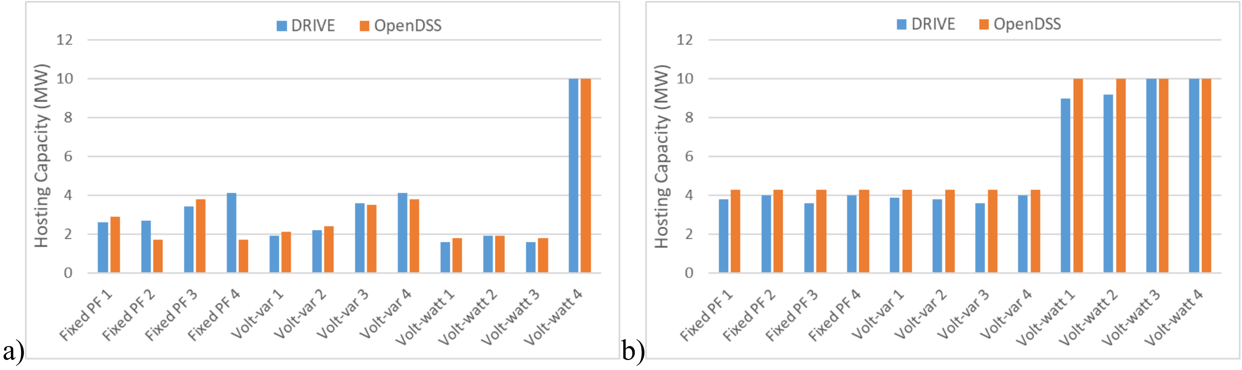
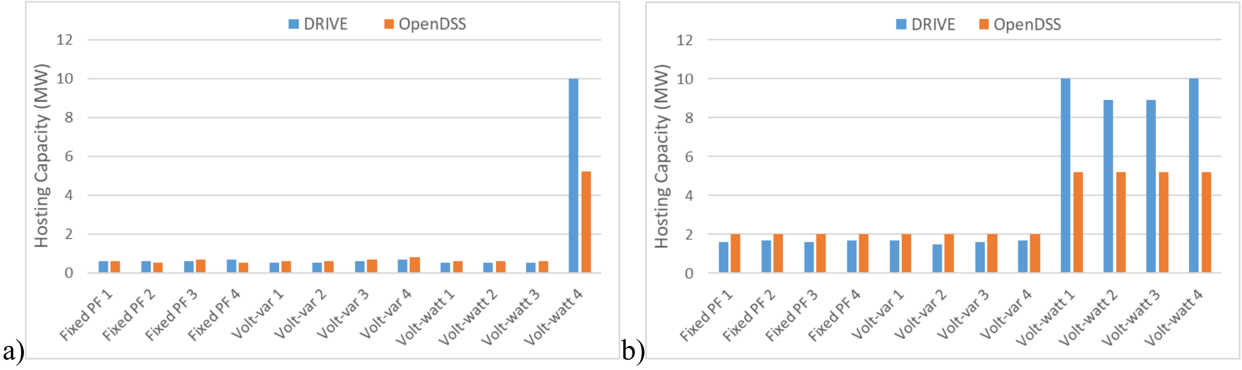


Figure 19. Feeder 105 Feeder-End Bus Results (a) Overvoltage and (b) Thermal



3.5 Summary

The overall results for the three performance assessments are quite similar even though the DRIVE mitigation module is not performing a detailed power flow analysis. Mismatch has been traced to underlying differences in solution algorithms and is within reasonable limits.

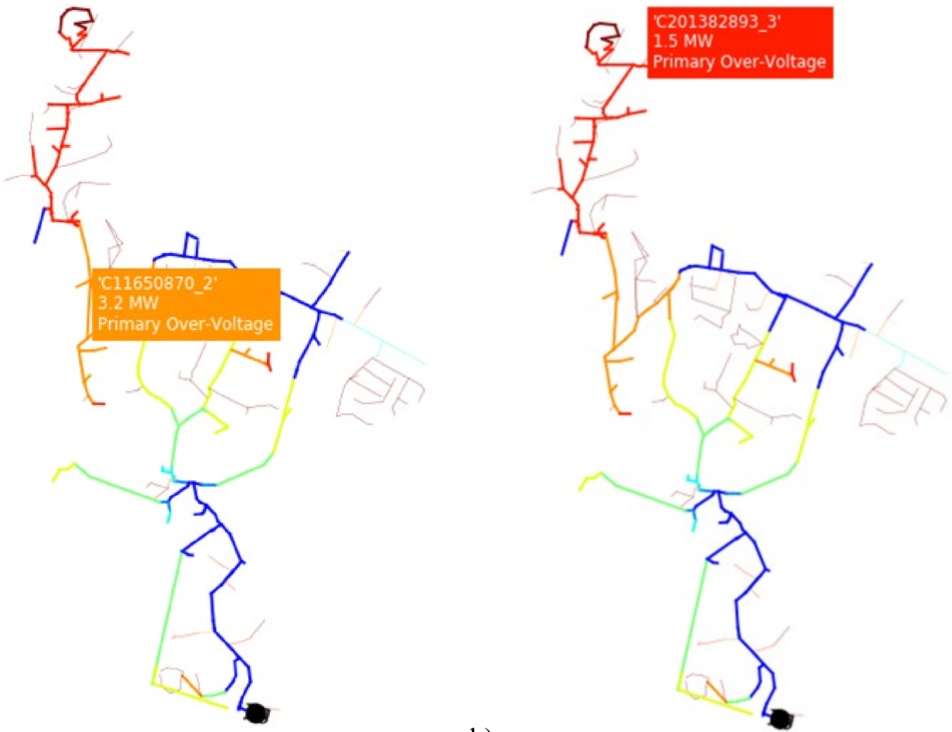
4 New York Implementation and Results

The final objective of the mitigation analysis project is to extend the analysis to a subset of New York State distribution feeders. This section examines the application of the mitigation analysis on a subset including three locations on two distribution feeders. Mitigation option settings applied are shown in section 2. Running the full mitigation analysis takes under a minute for each analyzed location.

4.1 Feeder A

The mid-feeder and feeder-end locations examined on Feeder A are shown in Figure 20. The heat map illustrates the overvoltage hosting capacity at the locations prior to mitigation analysis.

Figure 20. Feeder and PV Deployment Location (a) Mid-Feeder (b) Feeder-End



a) b)

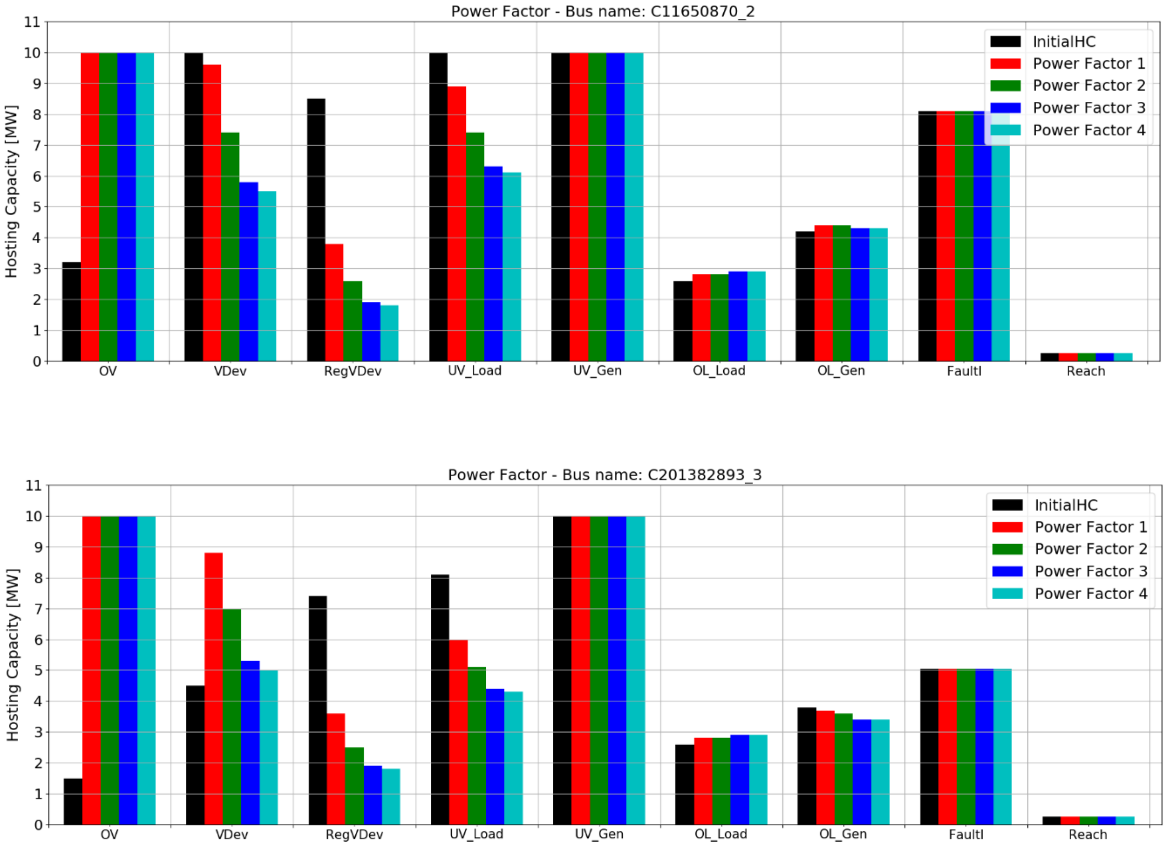
4.1.1 Power Factor

Inductive power factor greatly increases overvoltage (OV) hosting capacity as shown in Figure 21 for the mid-feeder and feeder-end locations. However, on this feeder, the mitigation option can decrease voltage deviation (VDev), regulator voltage deviation (RegVDev) and undervoltage for load (UV_Load) hosting capacity. Undervoltage for generation (UV_Gen), fault current (FaultI), and breaker reach (Reach) remains unchanged, while thermal for load (OL_Load) and thermal for generation (OL_Gen) are only slightly impacted. It is important to note that undervoltage for load and thermal for load examine the impacts of additional load (such as storage in its charging cycle) with inductive power factor. All other metrics focus solely on generation (source of power) impacts.

The voltage deviation, regulator deviation, and undervoltage for load hosting capacity results show that these settings greatly decreased the feeder voltage profile to the point of increasing the voltage change and the chance of having an undervoltage. Even though voltage profiles are depressed, undervoltage for generation is not an issue since the active power generation counters the voltage drop.

Thermal hosting capacity violations (OL_Load and OL_Gen) are not significantly impacted but changes in power flow and the specific location can cause an increase or decrease in hosting capacity based on the original reactive power flow direction.

Figure 21. Power Factor Results (a) Mid-Feeder (b) Feeder-End



a)

b)

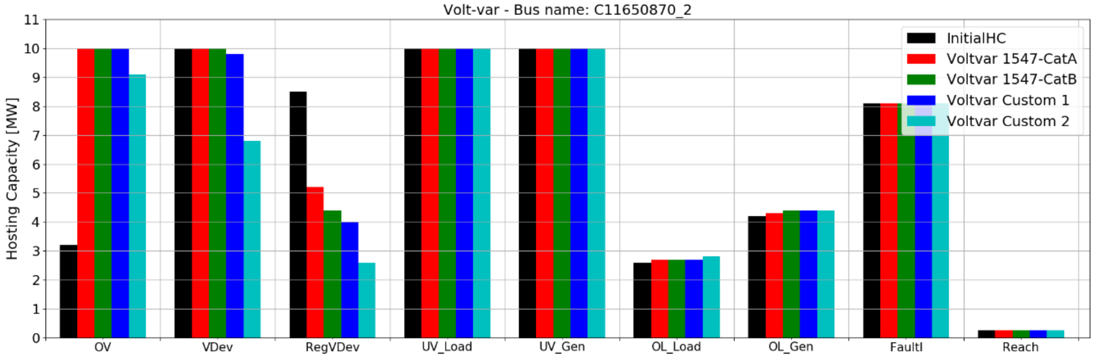
4.1.2 Volt-Var

Volt-var impacts the hosting capacity similar to power factor as shown in Figure 22. Even so, two main differences can be noticed due to the small diversity in the nature of those functions.

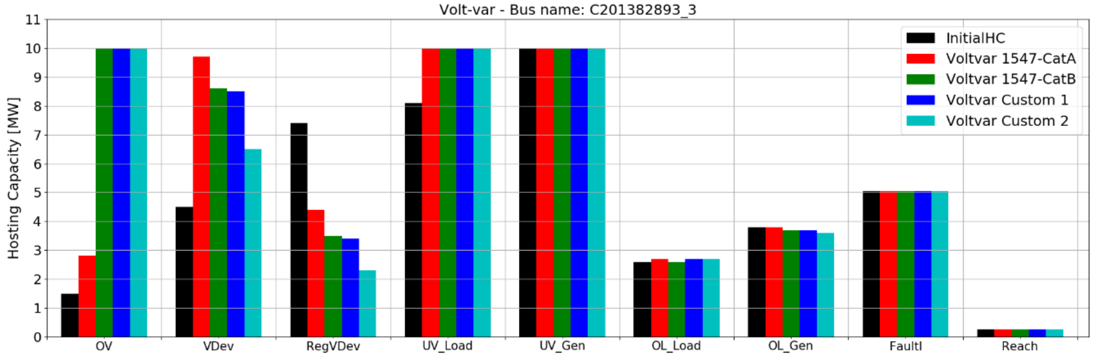
First, unlike power factor, volt-var control can provide reactive power during times of low voltage. For this reason, UV_Load results are the maximum value for all settings. Second, volt-var provides/absorbs reactive power as a function of the voltage at the point of connection while inductive power factor only absorbs reactive power which is a function of active power. As a result, volt-var can improve OV as much as power factor and has a better voltage deviation and regulator deviation impact due to the less reactive power absorption (reactive power absorption decreases as voltage profile is reduced).

It should be noted that at the feeder-end, the Volt-Var 1547-CatA setting does not have reactive power capability to be able to increase overvoltage hosting capacity as other settings do. At the same time, this CatA setting is the best in terms of increasing voltage deviation hosting capacity due to less reactive power demand.

Figure 22. Volt-Var Results (a) Mid-Feeder (b) Feeder-End



a)



b)

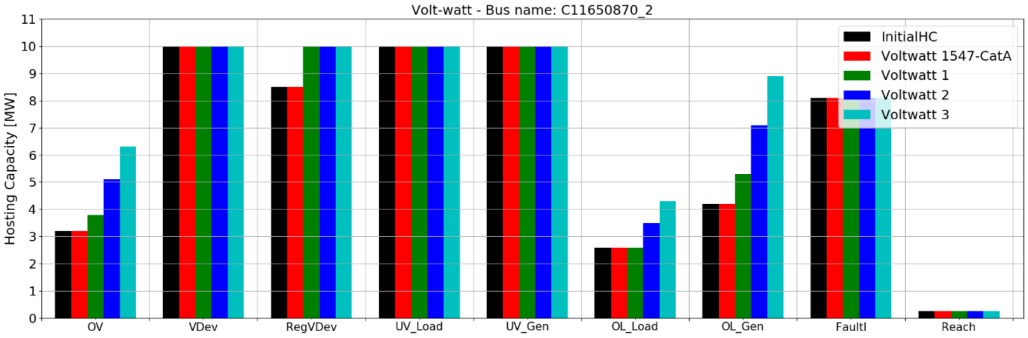
4.1.3 Volt-Watt

The volt-watt mitigation option increases overvoltage and thermal hosting capacities as shown in Figure 23. The impact to undervoltage and voltage deviation hosting capacities are location specific. This mitigation option does not change protection hosting capacities.

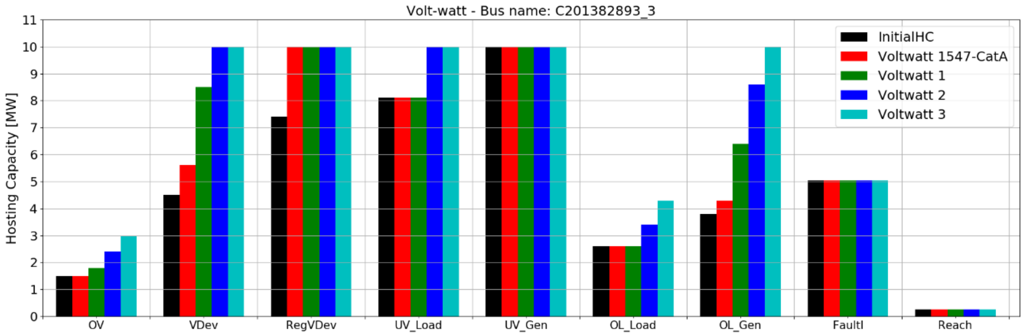
Volt-Watt 3 is the setting that best increases overvoltage hosting capacity. The setting is superior in this case because it starts curtailing generation when voltage reaches 1.0 Vpu, whereas the other settings start curtailing at higher voltage. Therefore, the setting is the one that curtails more generation and consequently the current that flows from the substation to PV deployment location remains the highest. For this reason, the setting also best increases thermal for generation hosting capacity, and additionally, thermal for load (OL_Load) hosting capacity can also slightly increase because load is being curtailed when the voltage is within ANSI limits.

It is also important to note that the Volt-Watt 1547-CatA does not change any hosting capacity violation when compared with InitialHC. In fact, the results are the same because volt-watt does not operate until the voltage reaches the overvoltage threshold.

Figure 23. Volt-Watt Results (a) Mid-Feeder (b) Feeder-End



a)



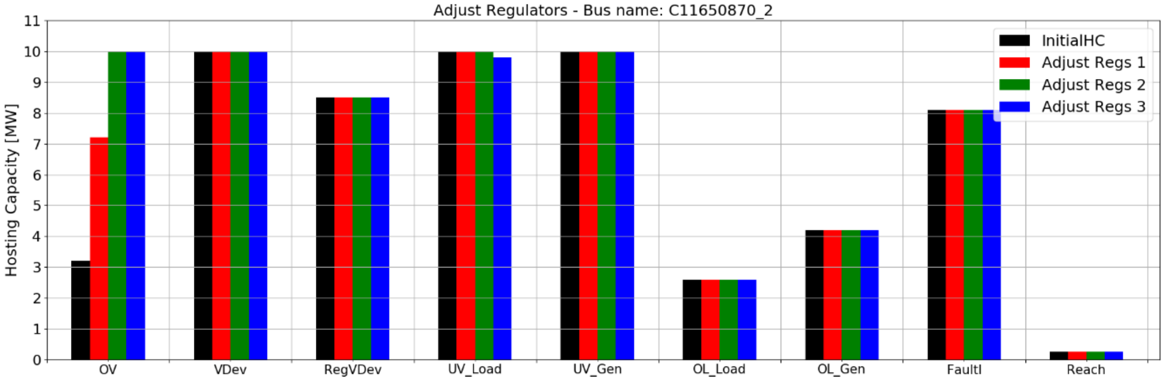
b)

4.1.4 Adjust Regulators

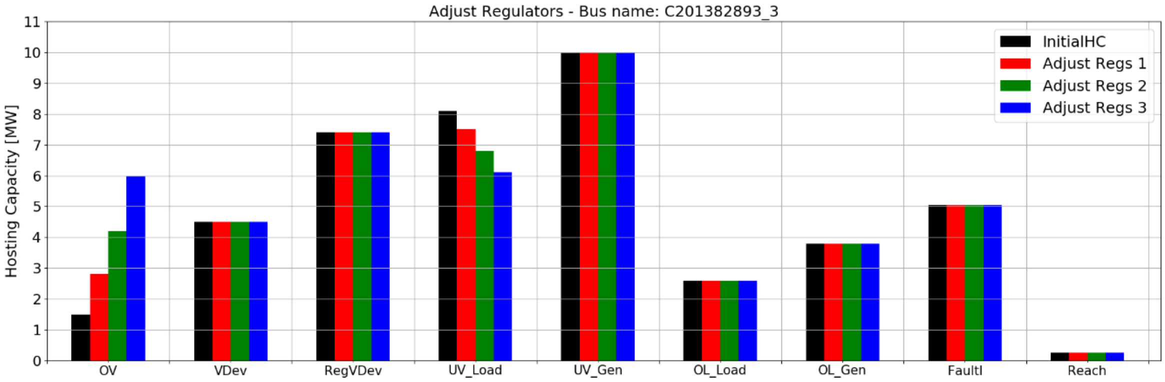
Adjusting the set points lower than the initial voltage of existing regulators on the feeder increases overvoltage and decreases undervoltage hosting capacity as shown in Figure 24. It is important to note that this mitigation option does not change voltage deviation, thermal, or the protection hosting capacities.

Lowering the set point with Adjust Regs 3 may increase the hosting capacity at the mid-feeder location the most, but it will inadvertently decrease the ability to accommodate more load at the feeder-end location. Therefore, the best mitigation option at one location may not necessarily be the best at another. The most suitable option(s) depends on the impacts at individual locations, which should be considered.

Figure 24. Adjust Regulators Results (a) Mid-Feeder (b) Feeder-End



a)



b)

4.1.5 Add Regulator

Figure 25 shows the results of adding a regulator upstream from the location selected. Adding a regulator upstream can impact overvoltage, undervoltage, and regulator voltage deviation hosting capacity. Adding the regulator further out from mainstream on the feeder (as occurs when examining the feeder-end location) results in a lower regulator voltage deviation hosting capacity.

Figure 25. Add Regulators Results (a) Mid-Feeder (b) Feeder-End

a)

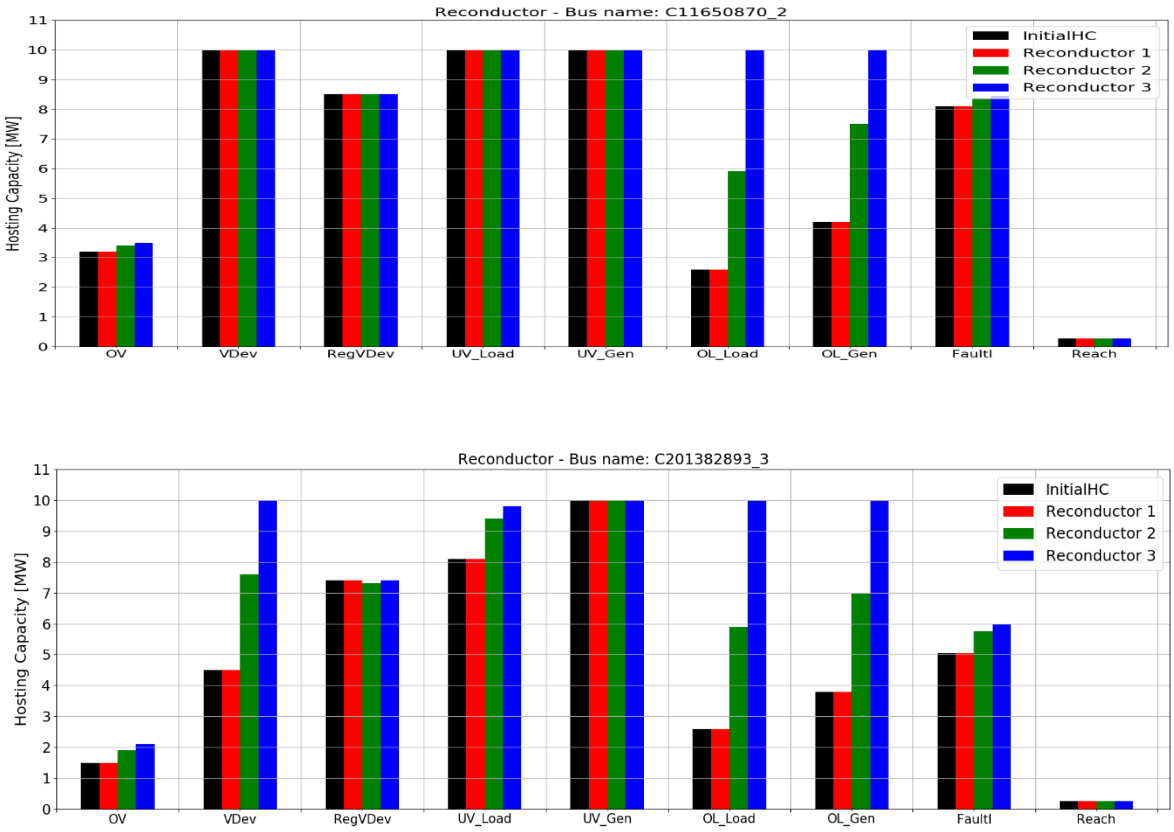
b)

4.1.6 Reconductor

Replacing the conductors upstream from the PV deployment location that have a rating lower than the conductors defined in the Reconductor settings allows higher currents to flow across those sections. Simultaneously, replacing those conductors with higher rated conductors can decrease the impedance and consequently the voltage drop across those sections. These changes can impact voltage, thermal, and protection-based hosting capacities. In this example, the mitigation options alter hosting capacities as shown in Figure 26.

It should be noted that the Reconductor 1 option does not change any hosting capacity when compared with the base case (InitialHC). This happens because the conductor rating of this option is less than the ratings on all sections upstream from the selected location.

Figure 26. Reconductor Results (a) Mid-Feeder (b) Feeder-End



a)

b)

4.1.7 Mitigation Options at Mid-Feeder

The mitigation options (from the 21 analyzed) are defined through two different approaches. In the first approach, they are defined according to the highest change in hosting capacity. In the second, they are defined according to the lowest annualized cost in dollar per change in hosting capacity. To determine the overall best mitigation option, only the overvoltage (OV), voltage deviation (Vdev), regulator voltage deviation (RegVDev), undervoltage for generation (UV_Gen) and thermal for generation (OL_Gen) metrics are considered.

4.1.7.1 Highest Change in Hosting Capacity

Change in hosting capacity is defined as the mitigation options limiting hosting capacity minus the base case's limiting hosting capacity. Limiting hosting capacity corresponds to the lowest hosting capacity value for metrics considered. Table 8 presents the hosting capacity results for the 21 mitigation options. Additionally, it shows the limiting hosting capacity and change in hosting capacity for each mitigation option and base case (InitialHC). It should be noted that some mitigation options decrease hosting capacity at this location.

Table 8. Hosting Capacity Results

Mitigation	Metric					Limiting HC	Change in HC
	OV	VDev	RegVDev	UV_Gen	OL_Gen		
InitialHC	3.2	10	8.5	10	4.2	3.2	
Power Factor 1	10	9.6	3.8	10	4.4	3.8	0.6
Power Factor 2	10	7.4	2.6	10	4.4	2.6	-0.6
Power Factor 3	10	5.8	1.9	10	4.3	1.9	-1.3
Power Factor 4	10	5.5	1.8	10	4.3	1.8	-1.4
Voltvar 1547-CatA	10	10	5.2	10	4.3	4.3	1.1
Voltvar 1547-CatB	10	10	4.4	10	4.4	4.4	1.2
Voltvar Custom 1	10	9.8	4	10	4.4	4	0.8
Voltvar Custom 2	9.1	6.8	2.6	10	4.4	2.6	-0.6
Voltwatt 1547-CatA	3.2	10	8.5	10	4.2	3.2	0
Voltwatt 1	3.8	10	10	10	5.3	3.8	0.6
Voltwatt 2	5.1	10	10	10	7.1	5.1	1.9
Voltwatt 3	6.3	10	10	10	8.9	6.3	3.1
Adjust Regs 1	7.2	10	8.5	10	4.2	4.2	1
Adjust Regs 2	10	10	8.5	10	4.2	4.2	1
Adjust Regs 3	10	10	8.5	10	4.2	4.2	1
New Reg 1	10	10	8.5	10	4.2	4.2	1
New Reg 2	10	10	8.5	10	4.2	4.2	1
New Reg 3	10	10	8.5	10	4.2	4.2	1
Reconductor 1	3.2	10	8.5	10	4.2	3.2	0
Reconductor 2	3.4	10	8.5	10	7.5	3.4	0.2
Reconductor 3	3.5	10	8.5	10	10	3.5	0.3

The change in hosting capacity column shows the amount of DER that the mitigation option can integrate over the base case and, as is evident, it can be negative depending on the mitigation option. This shows the importance of the mitigation option selection.

The three mitigation options that increase the hosting capacity most are as follows:

- Volt-Watt 3 option with 3.1 MW
- Volt-Watt 2 option with 1.9 MW
- Volt-Var 1547-CatB option with 1.2 MW

It should be noted that these best mitigation options are customer-side. The best grid-side mitigation options are Adjust Regs and New Reg with 1 MW. This occurs because overload for generation becomes the most limiting hosting capacity factor and grid-side options are ineffective at mitigating that metric.

4.1.7.2 Lowest Annualized Cost per Change in Hosting Capacity

A cost is associated to the utility to implement each mitigation option; therefore, the best mitigation option can be determined based on the annualized cost in dollars per change in hosting capacity in MW as shown in Table 9. Mitigation options that do not increase hosting capacity have been excluded. Costs might differ between utilities, so the numbers below are purely for illustration.

Table 9. Annualized Cost per Change in Hosting Capacity Results

Mitigation	Change in HC	Annualized Cost ($)	Annualized Cost per Change in HC
Power Factor 1	0.6	353.75	589.58
Voltvar 1547-CatA	1.1	238.26	216.60
Voltvar 1547-CatB	1.2	333.46	277.88
Voltvar Custom 1	0.8	346.24	432.80
Voltwatt 1	0.6	286.55	477.59
Voltwatt 2	1.9	872.55	459.24
Voltwatt 3	3.1	1435.51	463.07
Adjust Regs 1	1	46.71	46.71
Adjust Regs 2	1	46.71	46.71
Adjust Regs 3	1	46.71	46.71
New Reg 1	1	458.15	458.15
New Reg 2	1	458.15	458.15
New Reg 3	1	458.15	458.15
Reconductor 2	0.2	2064.99	10324.93
Reconductor 3	0.3	20640.86	68802.88

The three mitigation options that have the lowest annualized cost per change in hosting capacity are as follows:

- All Adjust Regs options with 46.71 $/MW
- Volt-Var 1547-CatA option with 216.69 $/MW
- Volt-Var 1547-CatB option with 277.88 $/MW

It is important to notice that the best mitigation options are different in both approaches except for volt-var 1547-CatB.

4.1.7.3 Combining Mitigation Options

Table 4-1 shows that a single mitigation option cannot improve all hosting capacity metrics. However, the table also indicates that some mitigation options make voltage hosting capacity better and some make thermal hosting capacity better. This suggests that two combined mitigation options might be better than one.

The two mitigation options—Volt-Watt 3 and Adjust Reg 2 or 3—are combined and its results are first estimated by considering them independently. However, this is a simplification. In fact, more accurate results can be obtained by simulating mitigation options together (future functionality). Table 10 presents the estimated impact of the combined mitigation options.

Table 10. Estimated Impact from Combined Mitigation Options

Mitigation	Metric					Limiting HC	Change in HC	Annualized Cost ($)	Annualized Cost per Change in HC
	OV	VDev	RegVDev	UV_Gen	OL_Gen				
Voltwatt 3	6.3	10	10	10	8.9	6.3	3.1	1435.51	463.07
Adjust Regs 3	10	10	8.5	10	4.2	4.2	1	46.71	46.71
Combined	10	10	10	10	8.9	8.9	5.7	1482.23	260.04

The combined mitigation option might increase hosting capacity by 5.7 MW which is higher than the individual mitigation option values. Its annualized cost per change in hosting capacity is just higher than the values of the two best mitigations options of the lowest cost per MW approach. This example indicates that combining mitigation options might be a beneficial alternative to treating the results independently as it cost effectively increases hosting capacity as well as demonstrates the need to include the examination of combined mitigation options in the assessment.

4.1.8 Mitigation Options at Feeder-End

The two approaches, highest change in hosting capacity and lowest annualized cost per change in hosting capacity, are applied to the mitigation analysis at the feeder-end location.

4.1.8.1 Highest Change in Hosting Capacity

Table 11 presents the hosting capacity results for the 21 mitigation options at the feeder-end location. It should be noted that no mitigation option decreases hosting capacity at this location. The three mitigation options that best increase the hosting capacity are as follows:

- All New Reg, Adjust Regs 2, and Adjust Regs 3 options with 2.3 MW
- Power Factor 1 option with 2.1 MW
- Volt-Var 1547-CatB option with 1.9 MW

It should also be noted that those mitigation options are completely different from the mid-feeder location's best mitigation options, except for Volt-Var 1547-CatB. At this location, both customer-side and grid-side options are included in the top three options. This shows that the PV deployment location can change the mitigation options that are most effective to increase hosting capacity.

Table 11. Hosting Capacity Results

Mitigation	Metric					Limiting HC	Change in HC
	OV	VDev	RegVDev	UV_Gen	OL_Gen		
InitialHC	1.5	4.5	7.4	10	3.8	1.5	
Power Factor 1	10	8.8	3.6	10	3.7	3.6	2.1
Power Factor 2	10	7	2.5	10	3.6	2.5	1
Power Factor 3	10	5.3	1.9	10	3.4	1.9	0.4
Power Factor 4	10	5	1.8	10	3.4	1.8	0.3
Voltvar 1547-CatA	2.8	9.7	4.4	10	3.8	2.8	1.3
Voltvar 1547-CatB	10	8.6	3.5	10	3.7	3.5	2
Voltvar Custom 1	10	8.5	3.4	10	3.7	3.4	1.9
Voltvar Custom 2	10	6.5	2.3	10	3.6	2.3	0.8
Voltwatt 1547-CatA	1.5	5.6	10	10	4.3	1.5	0
Voltwatt 1	1.8	8.5	10	10	6.4	1.8	0.3
Voltwatt 2	2.4	10	10	10	8.6	2.4	0.9
Voltwatt 3	3	10	10	10	10	3	1.5
Adjust Regs 1	2.8	4.5	7.4	10	3.8	2.8	1.3
Adjust Regs 2	4.2	4.5	7.4	10	3.8	3.8	2.3
Adjust Regs 3	6	4.5	7.4	10	3.8	3.8	2.3
New Reg 1	5.4	4.5	4	10	3.8	3.8	2.3
New Reg 2	10	4.5	4	10	3.8	3.8	2.3
New Reg 3	10	4.5	4	10	3.8	3.8	2.3
Reconductor 1	1.5	4.5	7.4	10	3.8	1.5	0
Reconductor 2	1.9	7.6	7.3	10	7	1.9	0.4
Reconductor 3	2.1	10	7.4	10	10	2.1	0.6

4.1.8.2 Lowest Annualized Cost per Change in Hosting Capacity

Table 12 presents the lowest annualized cost per change in hosting capacity for this location. The three best mitigation options that have the lowest annualized cost per change in hosting capacity are as follows:

- Adjust Regs 2 and Adjust Regs 3 options with 20.31 $/MW
- Adjust Reg 1 option with 35.93 $/MW
- Volt-Var 1547-CatA option with 135.57 $/MW

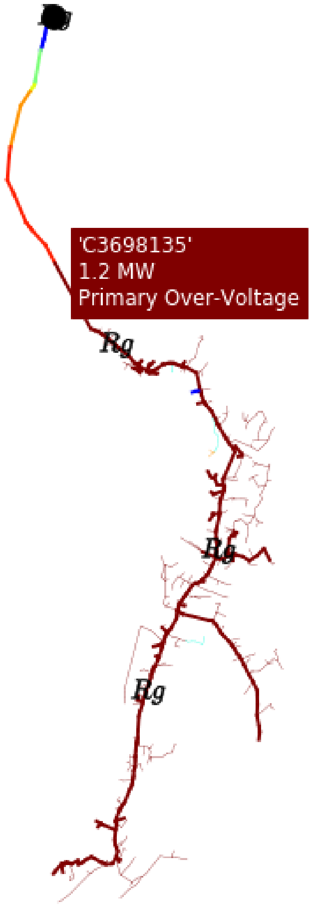
Table 12. Annualized Cost per Change in Hosting Capacity

Mitigation	Change in HC	Annualized Cost ($)	Annualized Cost per Change in HC
Power Factor 1	2.1	335.18	159.61
Power Factor 2	1	376.64	376.64
Power Factor 3	0.4	399.03	997.58
Power Factor 4	0.3	395.55	1318.49
Voltvar 1547-CatA	1.3	176.24	135.57
Voltvar 1547-CatB	2	338.99	169.49
Voltvar Custom 1	1.9	342.60	180.32
Voltvar Custom 2	0.8	376.14	470.17
Voltwatt 1	0.3	132.58	441.95
Voltwatt 2	0.9	406.57	451.75
Voltwatt 3	1.5	680.68	453.79
Adjust Regs 1	1.3	46.71	35.93
Adjust Regs 2	2.3	46.71	20.31
Adjust Regs 3	2.3	46.71	20.31
New Reg 1	2.3	458.15	199.19
New Reg 2	2.3	458.15	199.19
New Reg 3	2.3	458.15	199.19
Reconductor 2	0.4	11257.53	28143.83
Reconductor 3	0.6	112566.32	187610.53

4.2 Feeder B

The location examined on Feeder B is shown in Figure 27. The approaches to identify the best mitigation option are applied to this feeder location to determine if the best mitigation options are similar or not to the results of previous cases.

Figure 27. Feeder and PV Deployment Location



4.2.1 Highest Change in Hosting Capacity

Table 13 presents the change in hosting capacity for this feeder location. The three mitigation options that best increase the hosting capacity are as follows:

- Power Factor 1 and Volt-Var Custom 1 options with 2.9 MW
- Volt-Var 1547-CatB option with 1.8 MW
- Power Factor 2 and Volt-Var Custom 2 options with 1.5 MW

Compared to the previous location analyzed, the best mitigation options are different. The three best mitigation options are all customer-side solutions that impact voltage by absorbing reactive power. These options help increase regulator voltage deviation hosting capacity, which typically becomes the limiting hosting capacity for this feeder. With this in mind, one can conclude that this feeder is more sensible to reactive power. Further research might indicate that best options can be traced directly to the limiting hosting capacity.

It is also important to note that grid-side mitigation options are ineffective to increase overvoltage hosting capacity. In contrast to the previous cases, adjust regulator and add regulator cannot increase OV hosting capacity due to the violation occurring outside their regulation zone. Therefore, it shows that different locations as well as feeders might change the way the mitigation options impact hosting capacity.

Table 13. Hosting Capacity Results

Mitigation	Metric					Limiting HC	Change in HC
	OV	VDev	RegVDev	UV_Gen	OL_Gen		
InitialHC	1.2	7.4	1.6	10	5.6	1.2	
Power Factor 1	4.4	10	4.1	10	5.7	4.1	2.9
Power Factor 2	10	7.8	2.7	10	5.6	2.7	1.5
Power Factor 3	10	6	2	10	5.5	2	0.8
Power Factor 4	10	5.7	1.9	10	5.5	1.9	0.7
Voltvar 1547-CatA	1.9	10	2.7	10	5.7	1.9	0.7
Voltvar 1547-CatB	3	10	4.4	10	5.7	3	1.8
Voltvar Custom 1	4.2	10	4.1	10	5.7	4.1	2.9
Voltvar Custom 2	10	7.6	2.7	10	5.6	2.7	1.5
Voltwatt 1547-CatA	1.2	8.6	1.6	10	5.6	1.2	0
Voltwatt 1	1.3	10	1.7	10	8.4	1.3	0.1
Voltwatt 2	1.7	10	2.3	10	10	1.7	0.5
Voltwatt 3	2.1	10	2.9	10	10	2.1	0.9
Adjust Regs 1	3.1	7.4	1.6	10	5.6	1.6	0.4
Adjust Regs 2	5.2	7.4	1.6	10	5.6	1.6	0.4
Adjust Regs 3	8	7.4	1.6	10	5.6	1.6	0.4
New Reg 1	1.2	7.4	1.6	10	5.6	1.2	0
New Reg 2	1.2	7.4	1.6	10	5.6	1.2	0
New Reg 3	1.2	7.4	1.6	10	5.6	1.2	0
Reconductor 1	1.2	7.4	1.6	10	5.6	1.2	0
Reconductor 2	1.2	7.1	1.6	10	7.9	1.2	0
Reconductor 3	1.2	7.4	1.6	10	10	1.2	0

Lowest Annualized Cost per Change in Hosting Capacity

Table 14 presents the lowest annualized cost per change in hosting capacity for this feeder location. The three mitigation options that have the lowest annualized cost per change in hosting capacity are as follows:

- All Adjust Regs options with 116.79 $/MW
- Volt-Var Custom 1 option with 130.58 $/MW
- Power Factor 1 option with 131.58 $/MW

Even though Adjust Regs have a low change in hosting capacity, they are ideal because of their low cost. However, Volt-Var Custom 1 and Power Factor 1 are interesting because not only are they part of the best mitigation option, they are also the best mitigation option when changes in hosting capacity are considered. The Table shows that the change in hosting capacity options may be further justified by the annualized cost per change in hosting capacity as well.

Table 14. Annualized Cost per Change in Hosting Capacity

Mitigation	Change in HC	Annualized Cost ($)	Annualized Cost per Change in HC
Power Factor 1	2.9	381.59	131.58
Power Factor 2	1.5	406.69	271.13
Power Factor 3	0.8	419.98	524.98
Power Factor 4	0.7	417.47	596.38
Voltvar 1547-CatA	0.7	100.08	142.97
Voltvar 1547-CatB	1.8	241.44	134.13
Voltvar Custom 1	2.9	378.68	130.58
Voltvar Custom 2	1.5	414.70	276.47
Voltwatt 1	0.1	18.13	181.32
Voltwatt 2	0.5	210.95	421.90
Voltwatt 3	0.9	399.80	444.22
Adjust Regs 1	0.4	46.71	116.79
Adjust Regs 2	0.4	46.71	116.79
Adjust Regs 3	0.4	46.71	116.79

4.3 Summary

One mitigation option is not superior to other options to increase a feeder’s ability to integrate a higher penetration of DER. Just as hosting capacity is specific to location, device type, and individual metric, the change in hosting capacity is also specific to mitigation options. Finding ideal mitigation possibilities requires modeling and analysis of specific scenarios to gauge the level of benefit. The analytics developed in this project are meant to provide an automated method to make that observation without complicated detailed studies.

Results from this section 4 show the following:

- DER location changes the impact of the mitigation option to increase hosting capacity.
- Combining mitigation options is an advantageous alternative to increase hosting capacity further.
- The ideal mitigation option depends on how it is measured, such as overall improvement to hosting capacity or economically as the lowest utility cost per change in hosting capacity.

5 Conclusion

The penetration of medium-scale distributed energy resources (DER) such as photovoltaic systems in the electric distribution grid can lead to technical issues such as voltage violations and thermal overloads of the most expensive network assets (i.e., transformers and conductors). As these issues can limit the ability to accommodate higher penetration, developers and regulators are asking electric distribution utilities about the required upgrades to proceed with interconnection.

Grid impacts due to DER, however, vary considerably from distribution system to distribution system. Effective mitigation options are situation specific and are unique to the following:

- Size and location of the DER
- The impacted power system criteria
- Specific distribution system design and operating parameters
- Specific DER characteristics

A single mitigation option may not solve all power system criteria issues and hence a suite of integration options needs to be considered.

This research study developed new analytical methods that consider a suite of wire and technology-based mitigation options to increase hosting capacity. Simulations applied the analytical methods and demonstrated that effective integration solutions can be identified to achieve a desired penetration. The assessment methods can be incorporated with existing distribution planning software and would provide interconnection engineers with tools that would allow them to efficiently evaluate mitigation options and find integration solutions when requests exceed local hosting capacity. Several additional take-a-ways from this study include the following:

- Efficient methods have been developed to incorporate mitigation analysis with hosting capacity studies
- Validation studies show that developed methods are reasonably accurate to detailed studies
- Complexities brought about by mitigation-based hosting capacity studies should raise awareness to the fact that
    - Underlying algorithms will always be unique between tools
    - Functionality of control logic beyond the depth of an automated study can have an impact on final solutions (such as the voltage reference used by smart inverter control)
    - Some solutions can fail to converge in traditional power flow studies

Ultimately, efficient tools and methods can assist distribution planners to make educated decisions about the power system and DER, but detailed studies of situation-specific conditions will always remain necessary.

5.1 Technology Readiness Level

Prior to this research, efficient and effective methods combining mitigation and hosting capacity across an entire distribution system were not available. Through this project, efficient methods were developed to effectively assess multiple mitigation options across any distribution system. The project demonstrated a first-of-its-kind implementation in the EPRI DRIVE™ to show how this analysis can be performed utilizing existing planning models and data in New York State. Utility planners can begin to use this analysis to understand their current system and what mitigation options may be needed. Going forward further research to refine the method and mitigation options will lead to improved analytics.

5.2 Future Work

Mitigation hosting capacity can be further expanded. Two primary areas of interest include (1) an examination of additional mitigation options such as advanced capacitor control[10] and the combined mitigation options and (2) a determination of whether best mitigation options can be linked to the underlying issue(s) that restricts a location from accommodating DER.

Endnotes

[1] California Electric Rule 21 for Interconnection, http://www.cpuc.ca.gov/Rule21/

[2] Mitigation Methods to Increase Feeder Hosting Capacity. EPRI, Palo Alto, CA: 2018. 3002013382.

[3] https://www.epri.com/OpenDSS

[4] https://www.epri.com/DRIVE

[5] *Smart Inverter Functions & Settings for Distribution Applications*. EPRI, Palo Alto, CA. 2018. 3002013380

[6] *Incorporating DER into Distribution Planning*. EPRI, Palo Alto, CA: 2018. 3002010997

[7] This currently includes Cyme, Synergi, PowerFactory, DEW, Windmil/OpenDSS but can be expanded as long as the vendor tool can perform load flow studies and short circuit analyses.

[8] Extracting model information requires a separate Python script available through the EPRI DRIVE User Group.

[9] Mitigation Methods to Increase Feeder Hosting Capacity. EPRI, Palo Alto, CA: 2018. 3002013382.

[10] Mitigation Methods to Increase Feeder Hosting Capacity. EPRI, Palo Alto, CA: 2018. 3002013382.

New York State
Energy Research and
Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov

NEW YORK
STATE OF
OPPORTUNITY.™

NYSERDA

State of New York
Andrew M. Cuomo, Governor

New York State Energy Research and Development Authority
Richard L. Kauffman, Chair | Alicia Barton, President and CEO