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Increasing DER Hosting Capacity with Tie-Point Controllers

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SUMMARY

With increasing penetration of renewable generation and other distributed energy resources (DER), many utilities are looking for ways to safely and reliably increase DER hosting capacity (HC). Tie-Point Controllers offer one possible solution. A Tie-Point Controller, also referred to as a soft normally-open point (SNOP), is a power electronics device that is installed at a normally-open (NO) point between distribution systems and allows for dynamic, dispatchable and bidirectional real and reactive power (Watts, Vars) transfer. A SNOP's capability to transfer real and reactive power between distribution systems can allow for increased DER HC, increased load HC, improved reliability and reduced system losses by levelizing system loading and utilizing adjacent system capacity. Device benefits depend upon the location of the device in the distribution system, the available capacity on adjacent systems and how the device is controlled to achieve the desired objective(s). This paper discusses the specifications and operation of Switched Source LLC's Tie-Point Controller, how a device model was created in Eaton's power engineering software CYME, how a Tie Controller can be used to increase DER HC, and presents a case study where a Tie Controller was used to increase DER HC using a real world utility model and DER interconnections.

KEYWORDS

Dynamic Tie-Point Controller, Non-Wires Alternatives (NWA), Renewable Integration, Wind and Solar Integration, DER Integration, Smart Grid, Tie-Point Controller Modeling, Hosting Capacity.

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Introduction

Increasing distributed energy resource (DER) penetration presents new challenges for developers and utilities, and forecasts are showing continued growth in DER penetration over the next several years. ISO New England (ISO-NE) forecasts approximately 5,548 MW of distributed photovoltaic (PV) generation installations by the end of 2022 for the New England territory. This number is predicted to nearly double by the end of 2030, reaching 11,033 MW. Some states, such as Maine, are expected to see as much as 500% growth over the next 8 years [1]. Figure 1 displays a plot of the ISO-NE 2022 Distributed PV Forecast by state.

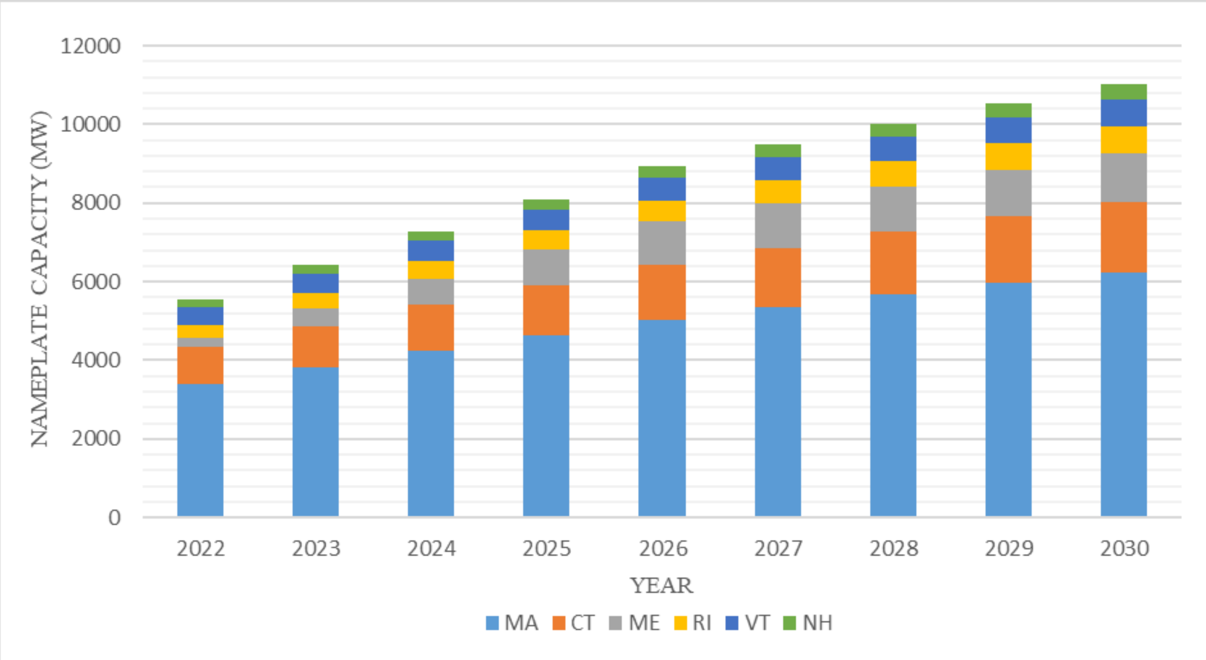

Figure 1: ISO-NE 2022 Distributed PV Forecast

Rising DER penetration and the need to facilitate existing customer DER interconnections has caused many utilities to look for methods to evaluate and increase hosting capacity (HC). DER HC is defined as the maximum amount of DER that can be supported without violating operational constraints [3]. Common safety or reliability concerns that limit HC are overvoltage conditions, volt/var device coordination, phase imbalance, thermal overloads, power quality issues, protection miscoordination, islanding, and various others [2,3,4,5,6,7,8]. Overvoltage conditions and thermal overloads are typically encountered first when attempting to increase DER HC, with overvoltage conditions being the most frequent occurrence [2]. Thermal overloads of conductors and substation transformers, while less frequent than overvoltage conditions, are relatively common under high DER penetration scenarios and may require cost prohibitive, “project-killing” upgrades.

Numerous methods have been proposed to increase DER hosting capacity. Some examples are voltage control coordination adjustments, grid reinforcements, dynamic reactive devices such as STATCOMs, smart inverter technology, active distribution network management systems (ADNMS), etc. [3,4,5,6,7]. Grid reinforcements, such as distribution line upgrades and substation transformer upgrades, increase thermal capacity and circuit stiffness; however, these upgrades tend to be very expensive. Adjustments to transformer on-load tap changers (OLTC), voltage regulators and switched capacitor bank controls have been used to improve voltage performance. However, the volatile nature of many DERs may increase device operations and lead to higher maintenance costs and reduced device lifespans. Dynamic reactive devices such as STATCOMs or smart inverter controls (e.g. Volt/Var regulation) have been used to effectively improve distribution system voltage performance, but are typically not effective at reducing thermal overloads.

This paper explores the utilization of Tie-Point Controllers as an additional means of increasing DER HC. Tie-Point Controllers, sometimes referred to as soft normally-open points (SNOPs), are power electronics devices installed at normally-open points between medium-voltage (MV) systems that allow for control of real and reactive power (Watts, Vars) transfer between distribution circuits [8]. A SNOP's capability to transfer real and reactive power between distribution systems can allow for increased DER HC, increased load HC, improved reliability and reduced system losses by levelizing system loading and utilizing adjacent system capacity. The ability to "push and pull" both real and reactive power across SNOPs allows Tie-Point Controllers to flexibly respond to dynamic system conditions and variable DER outputs. Additionally, the control of both real and reactive power can allow Tie-Point Controllers to address both the voltage and thermal issues that commonly limit DER HC.

The subsequent sections of this paper discuss the specifications and operation of Switched Source LLC's Tie-Point Controller (Tie Controller), how a device model was created in Eaton's power engineering software CYME, how a Tie Controller can be used to increase DER HC, and presents a case study where a Tie Controller was used to increase DER HC using a real world utility model and DER interconnections.

Tie-Point Controller Specifications, Operation, and Modeling

The Tie-Point Controller model that was used for this work was based upon Switch Source, LLC's Tie Controller. The Tie Controller is a power electronics device that is rated for up to 15 kV applications and a continuous current rating up to 450 A. The device's real and reactive power commands can be dispatched through supervisory control and data acquisition (SCADA), programmed to automatically respond to system conditions based on remote or local monitoring, or integrated with an ADNMS or distribution energy resource management systems (DERMS). The device can also be used in applications where the neighboring circuits have mismatched voltage magnitudes or phase angles allowing for greater application and flexibility between circuits that would otherwise have no tie capabilities. For example, a 12.5 kV circuit can be connected to an 8.3 kV circuit or two circuits with a 30° phase angle difference can be connected.

Eaton's CYME software does not currently have a built-in Tie-Point Controller model, so the device functionality must be modeled using existing architecture accompanied by custom programming scripts. To accomplish this, battery energy storage systems (BESS) were placed on either side of normally-open (N.O.) points where a Tie Controller was to be modeled, as shown in Figure 2.

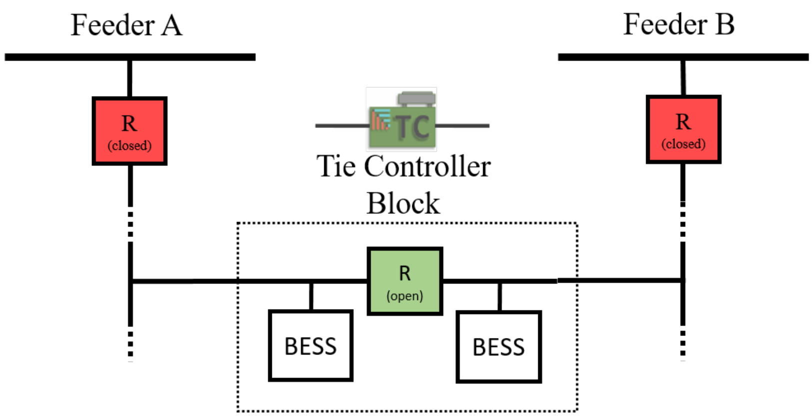

Figure 2: Tie Controller Representation in CYME

A BESS has the capability to both absorb and inject real and reactive power. Therefore, a coordinated pair of these devices is well suited for representing a Tie-Point Controller's capability to transfer power across a N.O. tie point by injecting power on one side of the device and consuming power on the other. Additionally, CYME has built-in Python Device Script functionality for BESS control, which allows for a convenient method of representing the automated control capability of the Tie Controller. A few examples of automated control schemes would be peak load shaving, maximum generation shaving and feeder balancing. In a load or generation shaving scheme, power flows are communicated to the Tie-Point Controller and the device transfers power between the circuits to ensure a preset power flow limit is not exceeded at the point of metering. In a load balancing scheme, the Tie-Point Controller receives power flow data from both circuits and determines the required power transfer to balance system loading.

An additional benefit of leveraging the built-in Python Device Script is that CYME's Long-Term Dynamics (time series simulation) module can be easily made compatible. Positive and negative spot loads were considered for a more simplistic Tie Controller representation. However, this would require external Python control as CYME does not have built-in Python Device Script capability for spot loads and would not allow for easy use of the Long-Term Dynamics module.

The following inputs are required for the Tie Controller representation:

- Thevenin equivalent short circuit resistance and inductance (Ω, H).
- Line-to-neutral phase voltages and angles (Volts, Radians).
- A control side command to determine which side of the device should maintain power transfer.
- The desired real and reactive power commands (Watts, Vars).

Figure 3 shows a diagram of the Tie Controller configuration with required inputs and outputs.

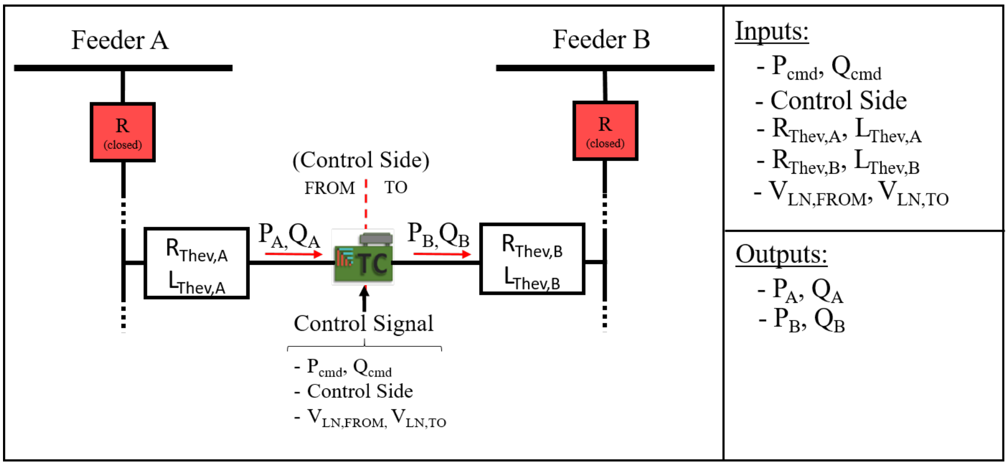

Figure 3: Tie Controller Configuration with Required Inputs and Outputs

Increasing DER Hosting Capacity via Tie-Point Controllers

DER interconnections are not typically evenly spread among distribution circuits and are subject to many factors such as land availability, availability of a three-phase service, permitting, etc. Due to the uneven distribution of DER, it's common to have neighboring circuits with very different DER penetration levels and available capacity. This is a scenario where a Tie-Point Controller may be effective in increasing HC.

Tie-Point Controllers can be used to address two common HC constraints: overvoltage conditions and thermal overloads. High penetration of DERs can result in voltage rise due to the injection of power into the distribution system and reverse power (export) conditions can create thermal overloads on upstream equipment. A Tie-Point Controller increases DER HC by transferring real power from a circuit with high DER penetration to a neighboring circuit with available hosting capacity. The device also has the capability to control reactive power to improve system voltages. This combination of real and reactive power transfer capability has been shown to be effective at increasing DER hosting capacity, especially when the DER sites are relatively close to the SNOP [8].

Similar to how the location of DER on a distribution system has a considerable impact on system HC, the location of a Tie-Point Controller, both in the system and relative to DERs, has a large impact on its ability to increase HC. For example, if a Tie-Point Controller is placed between two circuits directly outside of a substation, it's not going to reduce distribution line loading and may have a reduced ability to control voltage due to being located at a point with high system stiffness and near other regulating devices such as voltage regulators or on-load tap changers (OLTCs). However, if the two circuits are served by different transformers, this configuration may be effective at eliminating a thermal constraint on a distribution transformer. Thus, it is important to consider the application of a Tie-Point Controller based upon available locations where a SNOP can be created and system needs.

Case Study

A deterministic HC study [2] was performed on a 12.5 kV distribution network containing two radial circuits (Feeder A and Feeder B) using Eaton's CYME software. Feeder A, which is served by a 115/12.5 kV substation, is 30° out of phase with Feeder B, which is served by a 34.5/12.5 kV substation. The study focused on improving HC on Feeder A by leveraging available HC on Feeder B using a Tie-Point Controller. While HC improvements may be accomplished through upgrades such as line reconductoring, voltage control device upgrades, or other system reinforcements, a Tie-Point Controller was examined as a less costly non-wires alternative (NWA).

Three commercial PV sites were evaluated as DERs interconnecting to Feeder A:

- Site 1: 4 MW
- Site 2: 2 MW
- Site 3: 1.7 MW

Note that all PV sites were assumed to be operated at unity power factor (PF), thus only injecting real power into the system.

A summary of loading and generation parameters for each circuit can be seen in Table 1 and a geographic representation of the 12.5 kV distribution networks is shown in Figure 4.

Table 1: Case Study Load and Generation Summary

Circuit	Peak Load	Light Load	Nameplate DER
Feeder A	6.6 MW	1.7 MW	7.7 MW
Feeder B	5.0 MW	1.3 MW	0 MW

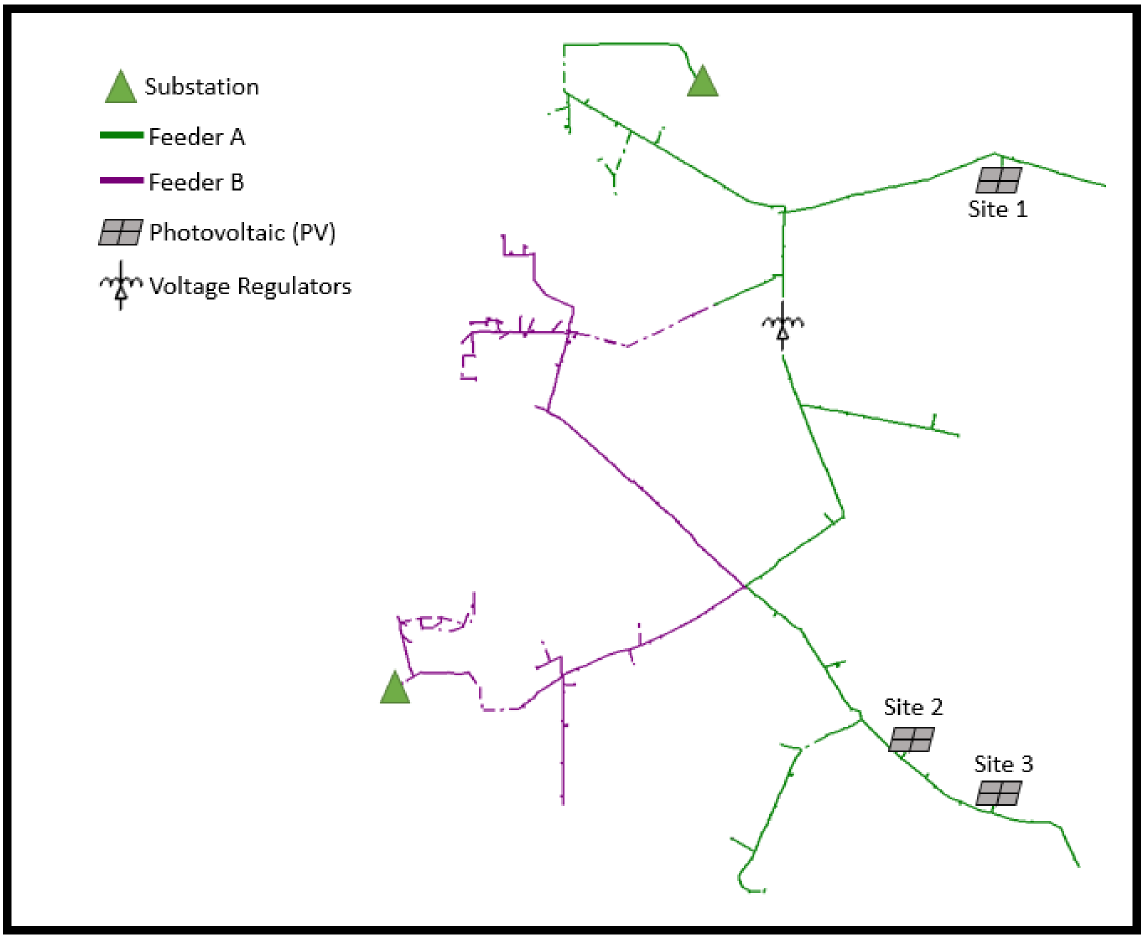

Figure 4: Case Study 12.5 kV Distribution Network Overview

Feeder A was first evaluated with the full 7.7 MW of DER online and no system upgrades considered. It was found that under lightly loaded conditions, the generation export resulted in high circuit voltages up to 107.8%, violating ANSI A high voltage criteria of 105% [9]. To resolve the high voltage violations, all three sites were curtailed to 15% of their respective outputs (approximately 1.2 MW total). The required 6.5 MW curtailment of PV to secure Feeder A voltages demonstrated a limited HC capability.

Feeder A has two locations with distribution lines in close proximity to a neighboring 12.5 kV circuit, Feeder B. The two locations are referred to as Tie #1 and Tie #2. It was empirically determined that placing the Tie-Point Controller at Tie #2 presented a more optimal scenario that allowed for greater HC compared to Tie #1. The tie locations and the Tie-Point Controller installation at Tie #2 can be seen in Figure 5.

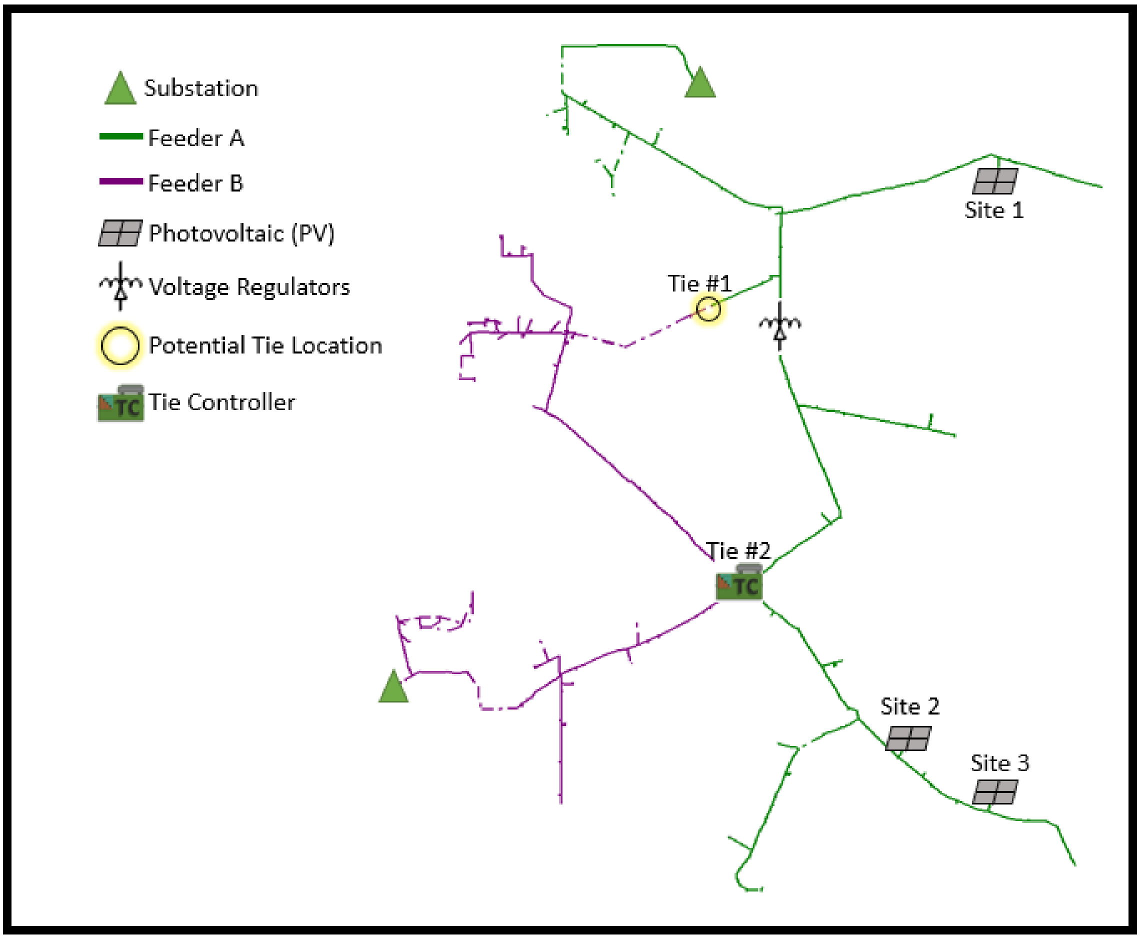

Figure 5: Potential Ties and Tie-Point Controller Installation Location

To mitigate the 107.8% high voltage violations that resulted under light load and maximum generation, the Tie-Point Controller was dispatched to transfer 5 MW and 2.5 MVAR from Feeder A to Feeder B, i.e. the device appears as a 5 MW and 2.5 MVAR load to Feeder A and a generator to Feeder B. Figure 6 shows a voltage heat map of Feeder A under existing system conditions and Figure 7 repeats this heat map with a Tie-Point Controller in service at Tie #2.

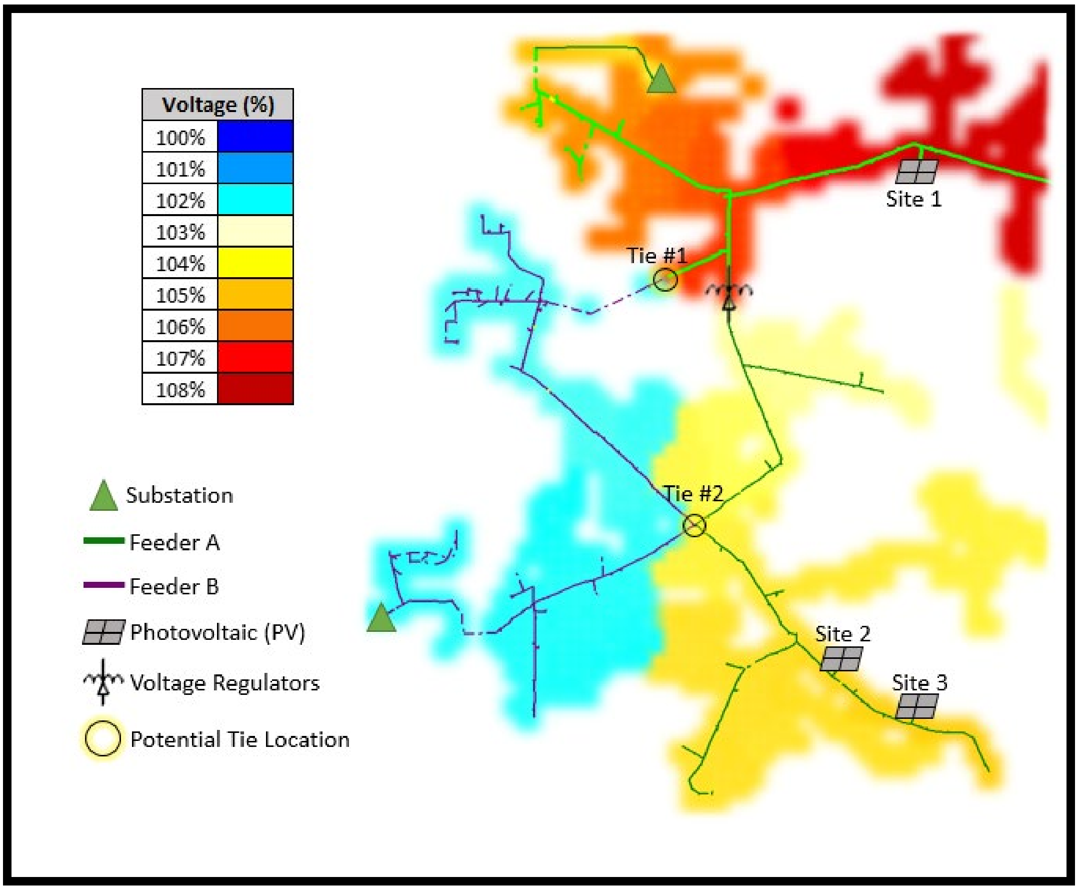

Figure 6: 7.7 MW of DER on Feeder A – Existing System

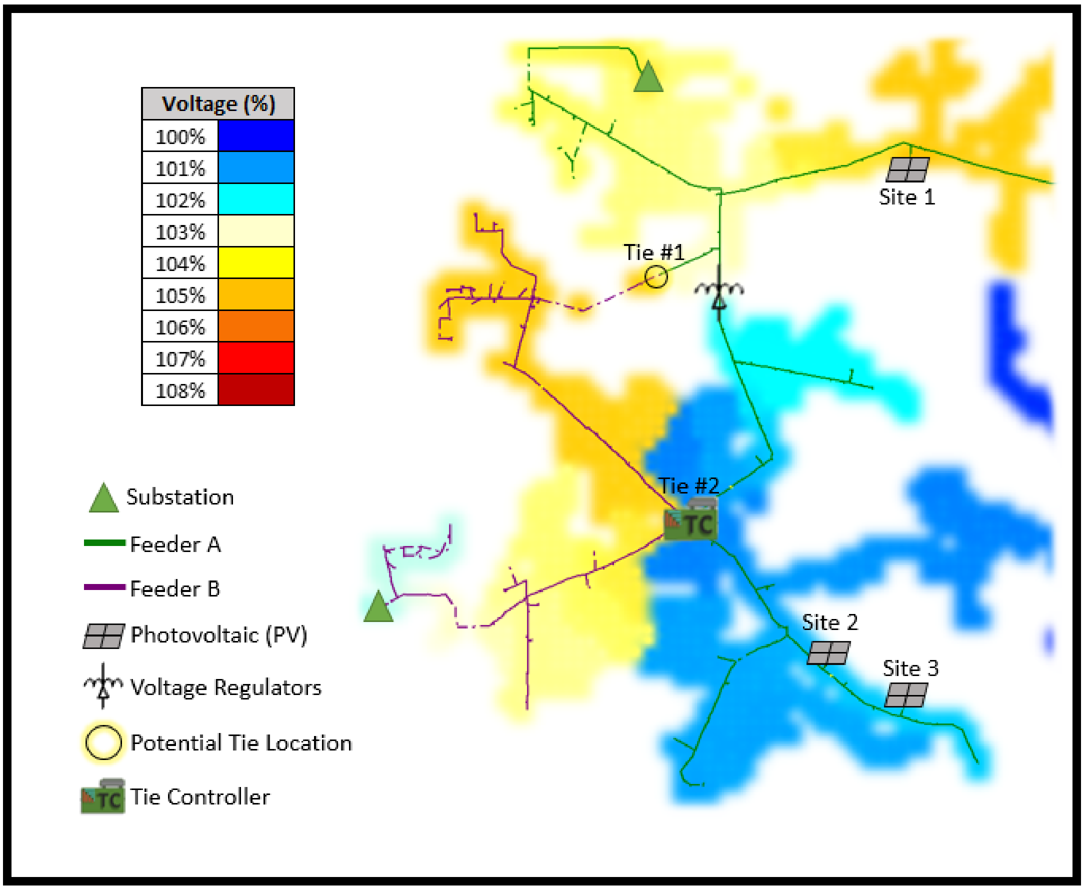

Figure 7: 7.7 MW of DER on Feeder A – With Tie-Point Controller

As shown, Feeder A voltages improve significantly with the use of a Tie-Point Controller. The "With Tie-Point Controller" scenario allowed for 100% of Feeder A's PV to be brought online without violating ANSI A high voltage criteria. These results show an increase from 1.2 MW of HC under existing system conditions to 7.7 MW with a Tie-Point Controller—an increase of approximately 567% or 6.5 MW.

To summarize the case study evaluation, an overview of voltage and thermal results under the light loading scenarios can be seen in Table 2.

Table 2: Case Study Thermal and Voltage Results

Circuit	Evaluation	Parameter	Existing System	With Tie-Point Controller
Feeder A	Voltage Levels (% of Nominal)	Highest	107.8%	104.9%
		Lowest	103.4%	100.3%
	Key Thermal Element Loading (% of Max)	Feeder A Substation Transformer	10.3%	5.2%
		Main Line Conductor*	77.4%	25.5%
Feeder B	Voltage Levels (% of Nominal)	Highest	102.4%	104.8%
		Lowest	102.1%	102.7%
	Key Thermal Element Loading (% of Max)	Feeder B Substation Transformer	19.9%	14.2%
		Main Line Conductor*	12.2%	38.3%

*The most limiting section of conductor in-line with the Tie-Point Controller was selected to show device impact.

It can be seen that Feeder B voltages increased with the transfer of 5 MW from Feeder A; however, voltages were adequately maintained under lightly loaded conditions with the highest voltage on the circuit reaching 104.8%. The pre- and post-Tie-Point Controller scenarios both showed acceptable thermal loading on Feeders A and B. Note that the Feeder B Substation Transformer experienced forward power flow (due to load) in the Existing System scenario and reverse power flow (due to the Tie-Point Controller injection) in the post-Tie-Point Controller scenario, hence the reduction in device loading.

Conclusions

This paper explores the use and efficacy of Tie-Point Controllers as a means of increasing DER hosting capacity and proposes a method of modeling the device in Eaton's power engineering software, CYME. It was found that Tie-Point Controller efficacy is dependent upon the location of the device in the distribution system, where the DER(s) are located relative to the device, and how the device is controlled; however, it has great potential for increasing DER hosting capacity. In one case study, a 567% (6.6 MW) increase in hosting capacity was observed. The flexibility to dynamically shift real and reactive power across SNOPs can be an effective tool in remediating voltage and thermal constraints [8] that limit hosting capacity. Thus, while Tie-Point Controller efficacy is dependent upon the application scenario, the device can be a valuable tool for the power system engineer's toolbox.

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