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# Improving DER Hosting Capacity with Tie-Point Controllers and Smart BESS

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## SUMMARY

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This document presents a comprehensive case study aimed at evaluating the benefits of implementing a Tie-Point Controller and Battery Energy Storage System (BESS) to enhance Distributed Energy Resource (DER) Hosting Capacity (HC) in distribution circuits. The study focused on a selected pair of 12 kV circuits (Feeder A and Feeder B) connected through multiple existing normally-open (N.O.) points, with Feeder B also hosting a 2,800 kW/5,600 kWh BESS.

Operational advantages of installing a Tie-Point Controller – namely, Switched Source's Tie Controller – were explored on the aforementioned circuits. The Tie Controller, a novel power electronic device with four-quadrant power capabilities, is designed to control real and reactive power flow between two N.O. points on the distribution system and has reactive power control capability similar to that of a distribution STATCOM. This document investigates the potential benefits of Tie Controller installations as well as various benefits associated with multiple BESS control modes. The BESS evaluation focused on two control methodologies: a time-of-day-based control scheme and a more complex voltage regulation scheme with DER peak shaving. Furthermore, the benefits of utilizing both devices simultaneously are explored.

This report provides a detailed breakdown of the modelling process, testing parameters, analyses conducted, and results obtained. The findings suggest that combining the Tie Controller and BESS yields significant improvements in DER HC, thus allowing for increased integration of renewable energy sources into the distribution system. Moreover, this combination demonstrates robust real-time voltage regulation capabilities, maintaining grid stability despite DER volatility.

## KEYWORDS

Tie-Point Controller, Battery Energy Storage System (BESS), Soft Normally-Open Points (SNOPs), Control Interactions, Non-Wires Alternatives (NWA), Renewable Integration, DER Integration, Smart Grid, Tie-Point Controller Modelling, Hosting Capacity.

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## Introduction

The mounting growth of distributed energy resources (DERs) continues to create new complexities for electric utilities, developers, and the industry as a whole. This trend will likely to persist in the foreseeable future, thus shaping the need for innovative solutions. ISO New England's (ISO-NE) projections indicate a significant surge in the deployment of distributed photovoltaic (PV) systems, predicting an output of 6,375 MW by the close of 2023 in the New England region. This figure is set to almost double by the conclusion of 2032, attaining a mark of 11,913 MW. Certain territories, such as Maine, are projected to witness a significant 300% growth within the next ten years [1]. A plot of the ISO-NE 2023 Distributed PV Forecast by New England state can be seen in Figure 1.

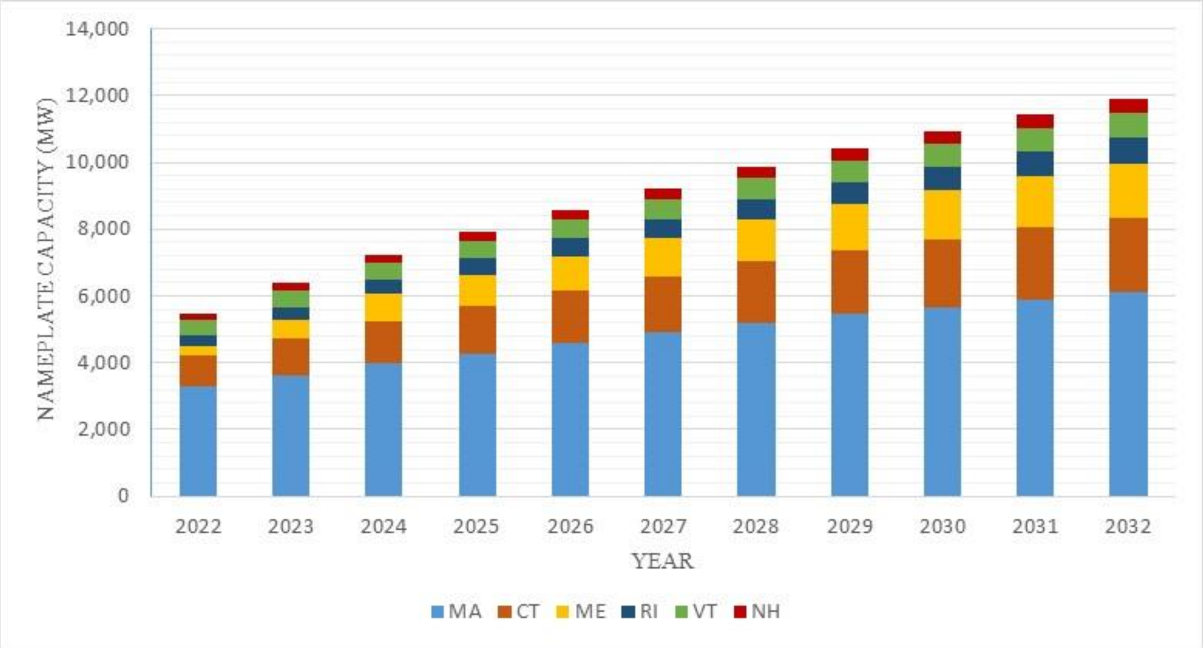


**Figure 1: ISO-NE 2023 Distributed PV Forecast**

As the DER footprint expands, utility providers must search for techniques to assess and improve hosting capacity (HC) to accommodate customer DER connections. DER HC refers to the maximum DER quantity a system can accommodate while staying within operational limitations [2]. Operational constraints surrounding DER HC frequently include thermal overloads, overvoltage conditions, miscoordination of protective devices, power quality issues, phase imbalances, and problems with Volt/Var device coordination, among others [2,3,4,5,6,7,8]. Overvoltage conditions exceeding the ANSI A high voltage criteria of 105% [9] are a common hurdle when attempting to enhance DER HC, and thermal overloads are also reasonably frequent when high DER penetration exists. Thermal overloads, in particular, could necessitate cost-intensive upgrades that may be prohibitive for some DER projects.

Several strategies have been suggested for improving DER HC. These may include adjustments to voltage control coordination, grid reinforcements, the deployment of dynamic reactive devices such as STATCOMs, the utilization of smart inverter technology, the use of storage technology such as battery energy storage systems (BESS), and active distribution network management systems (ADNMS) among others [3,4,5,6,7]. Despite the potential for grid reinforcements to increase thermal capacity and circuit stiffness, they tend to carry high price tags. Alterations to transformer load tap changers (LTC), voltage regulators, and switched capacitor bank controls can enhance voltage performance; however, the erratic nature of several DERs can lead to escalated maintenance costs and decreased device lifespan.

This document examines one promising strategy through the employment of Tie-Point Controllers as an additional measure for boosting DER HC. Also known as soft normally-open points (SNOPs), Tie-Point Controllers are power electronics devices deployed at normally-open (N.O.) points between medium-voltage (MV) systems to control the transfer of real and reactive power (Watts, Vars) between distribution circuits [8]. The ability of SNOPs to manage power transfer across distribution systems allows for an increase in both load and DER HC, improved reliability, minimized system losses through levelized system loading, and utilizing adjacent system capacity. The control of real and reactive power enables Tie-Point Controllers to effectively undertake both voltage and thermal issues that typically limit HC. Furthermore, reactive power control of these devices may aid in voltage stabilization and control coordination, similar to STATCOM functionality.

This document delves into the specifics and functionality of Switched Source, LLC's Tie-Point Controller (Tie Controller), the creation of a device model in Eaton's CYME power engineering software, how a Tie Controller can achieve DER HC improvements, how further increases to DER HC can be made through the use of a Tie Controller coupled with a separately located BESS, and a case study showcasing the application of the Tie Controller/BESS combination to increase DER HC using a real-world utility model and DER connections.

**Tie-Point Controller Overview**

Discussions, analyses, and results presented in this document are specific to Switched Source, LLC's Tie Controller [10]. This power electronics device may be utilized to dispatch fixed real and reactive power commands from one circuit to another; however, more sophisticated control may be achieved either locally or remotely via supervisory control and data acquisition (SCADA), ADNMS integration, or distribution energy resource management systems (DERMS). The Tie Controller offers added advantages by functioning effectively even when adjacent circuits exhibit different voltage levels or phase angles. This allows for improved interconnections and adaptability among circuits that cannot traditionally tie to one another. For example, a 12.5 kV circuit can be connected to an 8.3 kV circuit, or two circuits with a phase angle difference of 30° can be interconnected. The power electronics specifications of the Tie Controller can be viewed in Table 1.

**Table 1: Tie Controller Power Electronics Specifications**

| Parameter | Tie Controller Model Number | | |
|---|---|---|---|
| | **TC-15k133** | **TC-15k266** | **TC-15k450** |
| Current Rating | 133 A | 266 A | 450 A |
| Interconnection Voltage | 15 kV 3 Phase | | |
| Power Rating at 15 kV | 3.5 MVA | 6.9 MVA | 10.3 MVA |
| Operating Voltage | 4 - 14 kV | | |
| Operating Frequency | 50, 60 Hz | | |
| Phase Angle Mismatch | 0° - 90° | | |
| Power Factor Range | ±0.90 | | |
| LVRT | Optional | | |
| $I_{SC}$ (Optional, 30 cycles) | 266 A | 400 A | 400 A |

The Switched Source Tie Controller demonstrates particular strengths in managing high load, high DER penetration, or a combination of both situations. The device's ability to dynamically balance power across multiple circuits can help manage intermittency issues from DERs while reducing the risk of outages due to high load demand.

Additionally, the Tie Controller contributes to energy efficiency in the distribution network. It's equipped to optimize power flows and minimize line losses, enabling better asset utilization without the need for costly infrastructure upgrades. These features allow for improved utilization of existing assets, potentially bypassing or deferring the need for costly infrastructure upgrades. Moreover, the device's design exhibits substantial durability due to its industrially hardened components and systems, enabling it to withstand field operations effectively.

The flexibility of the Tie Controller is underscored by its software-configurable nature. It can accommodate multiple applications that can be modified as system requirements evolve. Applications range from peak shaving and voltage support to enhanced DER integration. The compatibility of the Tie Controller with SCADA and DERMS systems aligns with the need for adaptability in modern and future power distribution networks. This compatibility allows the Tie Controller to play multiple roles within an operator's toolkit, reinforcing the system against present and future challenges.

**Assessing Locations**

Various factors should be considered when selecting the optimal location for installing a Tie Controller. Firstly, it is essential to ensure the application voltages are 15 kV or below, given that the Tie Controller device is rated for and limited to applications of this voltage. Next, any existing N.O. tie locations that may be suitable for the device should be initially evaluated as such points can make ideal locations for device installation and typically demand little additional infrastructure to support the device. Available space may also be a factor for some locations as the Tie Controller’s physical footprint is approximately 96 in. x 75 in. x 50 in., which is likely not an issue in many rural settings, but may be infeasible in some urban areas.

The intended purpose of the Tie Controller also influences its installation location. Placement may vary depending on whether the goal is to increase DER HC, enhance load HC, or augment feeder backup scheme capacities. For example, to increase DER HC, the Tie Controller can distribute generation from a circuit with high DER penetration to another with more capacity, thereby equalizing power flows and enhancing overall DER HC. The Tie Controller can import power from a neighboring circuit with available capacity to boost load HC, leading to balanced circuit loads and increased total load HC. For enhancing feeder backup schemes, the Tie Controller can establish a link to a separate third feeder that is not presently included in the current backup scheme used between two other feeders. This integration augments the load-serving ability in backup scenarios and alleviates restrictions associated with maintenance windows.

Other important considerations include the existing circuit voltage profiles, system stiffness, and thermal capacity of potential installation locations. Like DER or large load interconnections, full capacity realization may only be possible if the local electric power system (EPS) can accommodate the power injection and/or absorption. While the Tie Controller's primary role is to mitigate or delay the need for DER or load-driven upgrades, it is critical to conduct thorough studies to ensure that its installation will not result in any criteria violations. For instance, a N.O. point with small circuit conductors may not allow for the planned capacity transfer between circuits, leading to new thermal overloading concerns. Hence, locations that do not require additional infrastructure upgrades to accommodate the Tie Controller interconnection are typically the most desirable.

**Tie-Point Controller Modelling**

Eaton’s CYME software does not have a pre-built model for a Tie-Point Controller; however, it is still possible to emulate its functionality by blending the software's existing framework and tailor-made programming scripts. Namely, CYME’s BESS model is a fitting representation of a Tie-Point Controller, as it can both absorb and inject real and reactive power. Coordinating two BESS models on either side of a N.O. point can emulate the Tie-Point Controller's function of transferring power between circuits by injecting power on one side while absorbing it on the other.

CYME's built-in Python Device Script feature for BESS control serves as a suitable way to model the automated control capability of Switched Source’s Tie Controller. These automated control strategies can involve peak load shaving, maximum generation shaving, and feeder balancing, to name a few. For load or generation shaving strategies, the Tie Controller receives power flow instructions and subsequently redistributes power between the circuits to prevent exceeding a predefined power flow limit at the metering point. In feeder balancing strategies, the Tie Controller processes power flow data from both circuits to ascertain the necessary power transfer to balance system loading.

A significant benefit of using the built-in Python Device Script is its seamless compatibility with CYME's Long Term Dynamics module, which is utilized for time series simulations. Initially, positive and negative spot loads were evaluated for a simpler representation of the Tie Controller. However, this approach would require external Python control due to CYME's lack of built-in Python Device Script support for spot loads, making it a less suitable choice for integrating with the Long Term Dynamics module.

Specific inputs are necessary for proper Tie Controller modeling. These inputs include:

- The specified real and reactive power commands (in Watts and Vars)
- A control side command identifying which device side will maintain power transfer
- Thevenin equivalent short circuit resistance and inductance on both sides of the device (in Ω and H)
- Measured line-to-neutral phase voltages and angles on both sides of the device (in Volts and Radians)

Figure 2 provides a detailed visualization of the Tie Controller configuration, showing the required inputs and corresponding outputs.

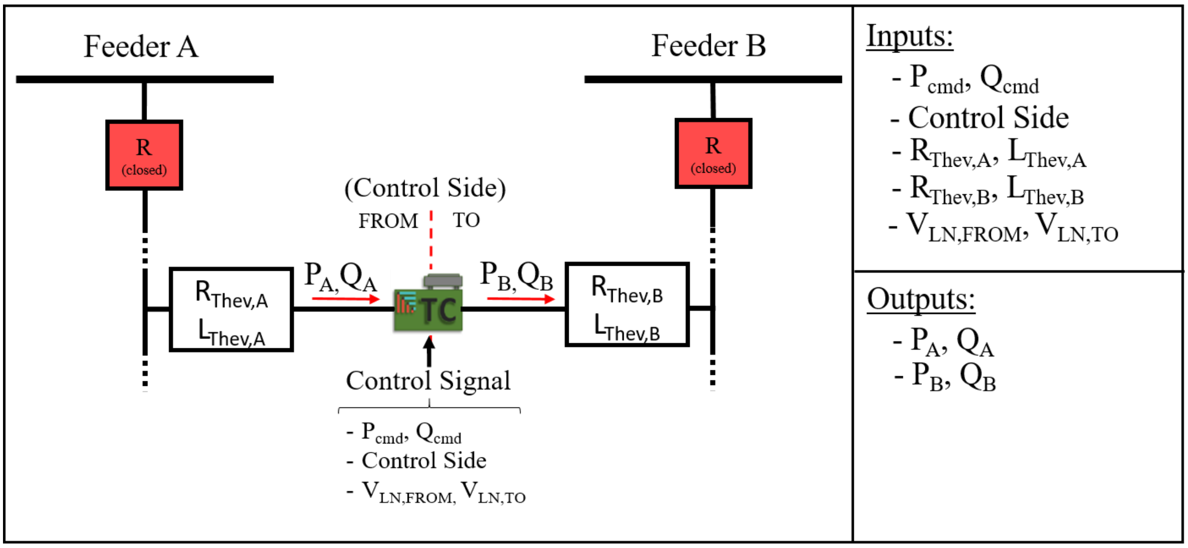


**Figure 2: Tie Controller Representation With Inputs and Outputs**

It should be noted that Tie Controller outputs are dictated by proprietary device control algorithms, which are represented in the black-boxed Python code.

**Case Study Description**

A case study was performed on a 12 kV distribution network containing three radial circuits: Feeder A, Feeder B, and Feeder C. Loading and generation characteristics for these circuits can be seen in Table 2.

**Table 2: Case Study Network Loading and Generation**

| Circuit | Peak Load (kVA) | Light Load (kVA) | Total Nameplate DER (kW) | Number of DER ≥ 500 kW | Number of DER < 500 kW |
|---|---|---|---|---|---|
| Feeder A | 3,364 | 1,009 | 3,836 | 1 | 112 |
| Feeder B | 3,800 | 1,140 | 9,814 | 7 | 60 |
| Feeder C | 1,772 | 532 | 8,146 | 4 | 7 |

This study aimed to evaluate the application of a TC-15k133 (see Table 1) Tie Controller in tandem with an existing 2,800 kW/5,600 kWh energy storage device located on Feeder B. The goal was to enhance the DER HC, load HC, and improve feeder restoration capability. This assessment involved three key elements: identifying potential device installation locations, modeling the Tie Controller, and evaluating the distribution system under various configurations to measure system hosting capacity and reliability benefits. While all areas of the evaluation showed promising results, this document primarily focuses on DER HC improvements. To that end, Feeders A and B are this document's primary focus; however, Feeder C was incorporated during the feeder restoration evaluation.

In the initial phase, three (3) areas were identified as potential sites for the Tie Controller's installation. Two (2) of these were existing N.O. points between the Feeder A and Feeder B circuits, chosen for their potential cost savings related to interconnection. The third area was chosen due to its relatively close proximity to both circuits despite the absence of an N.O. tie point. These potential Tie Controller locations, as well as the aforementioned BESS site, can be seen in Figure 3.

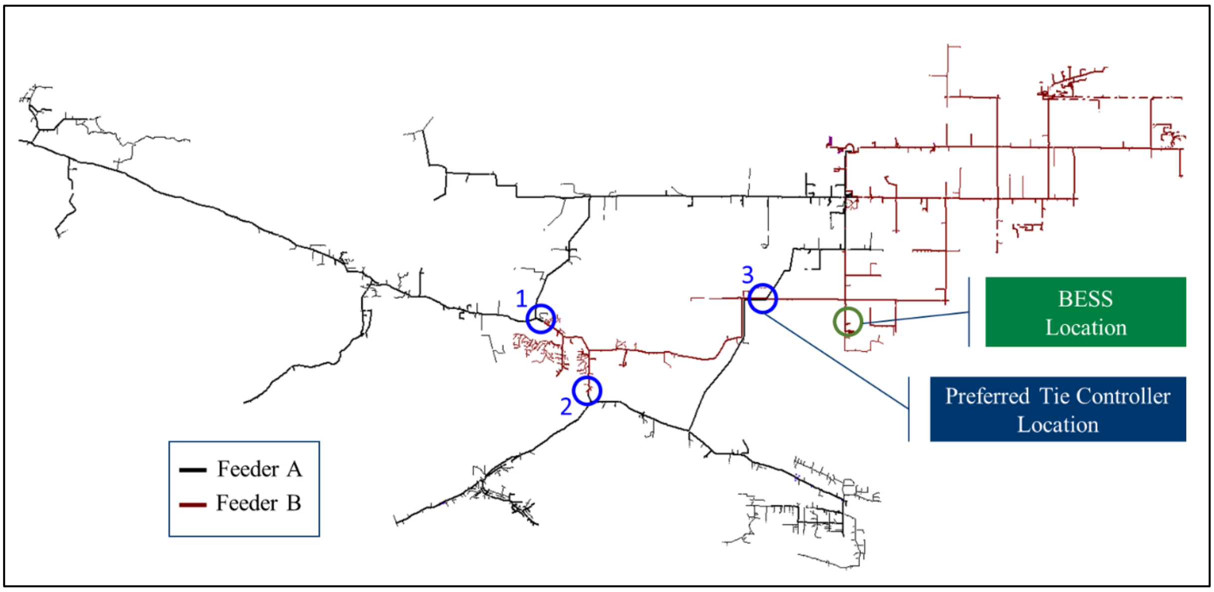


**Figure 3: Potential Tie Controller Locations**

Locations 1 and 2 were initially examined due to the existing N.O. points. However, both sites possessed low stiffness characteristics, limiting their power transfer capability. Upon further evaluation, Location 3 emerged as the most suitable site for the Tie Controller, owing to its relatively high system stiffness on Feeders A and B. Its proximity to the BESS allowed for a more synergistic operation with the Tie Controller. This location was approximately 5.5 miles from the substation via the Feeder B circuit and 5.1 miles via the Feeder A circuit.

For the DER HC evaluation, DER in the model was scaled based on a percentage of nameplate capacity. For instance, a 5.0 MW nameplate-rated PV site would produce 2.5 MW at a 50% DER scale factor. The Feeder A and Feeder B circuits were modeled under light load conditions, assuming 30% peak load, and all load flow simulations were completed using the "Voltage Drop – Balanced" calculation method with assumed Source Impedance enabled to increase simulation accuracy. Note that the "Voltage Drop – Unbalanced" calculation method is most often used for Tie Controller simulations; however, the provided model was postured such that the "Voltage Drop – Balanced" method would be most suitable.

The existing BESS currently operates in an open-loop, time-based fashion. Due to the pre-existing large PV DER penetration on the Feeder B circuit, the BESS is set to charge at full capacity (2,800 kW) for two (2) hours (5,600 kWh) mid-day, when PV DER is expected to generate near maximum capacity, and discharge at the same rate in the evening when customer loads are high, but PV DER outputs are low. An additional operating mode was also tested for the BESS in this study. This involved local voltage regulation, a remote load/DER peak shaving scheme based on feeder head values, and a maximum charge/discharge value of 700 kW such that a continuous eight (8) hours of capacity could be relied upon for use. The time-based operation is referred to as “BESS (Timed)” and the more complex operating mode as “BESS (Smart)” for the remainder of this document.

**Case Study Analysis and Results**

With system modeling parameters established in the previous section, six (6) variants of analyses were conducted in this case study:

1. Existing system, BESS offline
2. Tie Controller only
3. BESS (Timed)
4. BESS (Smart)
5. Tie Controller + BESS (Timed)
6. Tie Controller + BESS (Smart)

All six (6) variants were analyzed from a steady state perspective. The efficacy of each variant was determined by the following simplified equation for HC:

$$\text{Hosting Capacity (\%)} = \frac{\text{Allowable Generation (kVA)}}{\text{Circuit Peak Load (kVA)}}$$

It should be noted that HC is a complex characteristic to measure and an industry consensus has not yet been reached on a universal metric for conveying increases. However, this equation serves as a high level method for quantifying DER increases above the baseline value through the use of the Tie Controller and/or BESS.

The steady state DER HC evaluation captured real and reactive power flows at the head of Feeder A, the head of Feeder B, BESS terminals, and Tie Controller terminals on both circuits. These results are shown in Table 3:

**Table 3: Steady State DER HC Results**

| Metrics | Test Variants | | | | | |
|---|---|---|---|---|---|---|
| | Existing System (BESS Off) | BESS (Timed)† | BESS (Smart) | Tie Controller | Tie Controller + BESS (Timed)† | Tie Controller + BESS (Smart) |
| **DER Scale %*** | 50% | 80% | 125% | 125% | 130% | **170%** |
| **HC %** | 140% | 224% | 351% | 351% | 365% | **477%** |
| **Feeder A Head kW** | -971 | -2,112 | -3,797 | -4,763 | -4,949 | **-7,316** |
| **Feeder A Head kVAR** | 145 | 165 | 245 | 280 | 289 | **1,413** |
| **Feeder B Head kW** | -3,789 | -3,910 | -10,050 | -9,765 | -7,610 | **-12,235** |
| **Feeder B Head kVAR** | 277 | 326 | 2,831 | 2,602 | 1,706 | **2,708** |
| **BESS kW** | - | -2,800 | -700 | - | -2,800 | **-700** |
| **BESS kVAR** | - | 0 | -1,749 | - | 0 | **-1,224** |
| **Tie Controller Feeder A kW** | - | - | - | -1,000 | -1,000 | **-2,000** |
| **Tie Controller Feeder A kVAR** | - | - | - | 19 | 19 | **-824** |
| **Tie Controller Feeder B kW** | - | - | - | 1,000 | 1,000 | **2,000** |
| **Tie Controller Feeder B kVAR** | - | - | - | -1,552 | -957 | **74** |

* DER Scale % reflects the percent of nameplate that was used during testing.
† BESS (Timed) scenario reflects maximum charge (2,800 kW), which can only be sustained for up to 2 hours, assuming 0 initial charge and a maximum capacity of 5,600 kWh.

As shown, the Tie Controller + BESS (Smart) variant showed the largest increase in DER HC at 477%, thus allowing for a DER increase of 6,345 kW on Feeder A and 8,446 kW on Feeder B when compared to the Existing System (BESS Off) variant. Note that both circuits were primarily limited by overvoltage violations and thus, both devices were most impactful by reducing circuit voltages to alleviate these violations. It can also be seen that the DER Scale % of the Existing System (BESS Off) variant was 50%, which can be attributed to the majority of the circuit DER being PV units. These sites peak mid-day when system loads are also high; however, this analysis was conducted using light loading values (30% of peak), and therefore, full DER nameplate outputs could not be achieved at these conservative levels in this variant.

Operationally, each device was set with multiple functions, which were unique to each test variant. For the Tie Controller + BESS (Smart) variant in particular, the Tie Controller was set to regulate 101% voltage at its Feeder A interconnection point and to limit the Feeder B head to 2,000 kW of reverse flow. The BESS was controlled to regulate 102% voltage at its Feeder B interconnection point and to limit the Feeder B head reverse flow to 7,500 kW of reverse flow. Due to the Tie Controller having a much lower reverse flow limit at the same remote point as the BESS, it injected real power into its Feeder B interconnection point and reached maximum capacity (approximately 2,000 kW) before the BESS used any of its real power capabilities (up to 700 kW) by design such that predictability could be increased, and uncertainty of BESS energy stored at any given time was reduced. Furthermore, the Tie Controller regulated voltage on its Feeder A side and the BESS regulated its Feeder B interconnection point with the purpose of having fast-acting regulation schemes on both circuits.

While the previous results presented device voltage regulation capabilities during steady state conditions, they lacked the ability to showcase the capability for dynamically responding to volatile grid conditions due to DER fluctuations and shifting loads. Therefore, the Tie Controller + BESS (Smart) variant was further evaluated for the effectiveness of voltage stabilization via time series evaluation using CYME’s Long Term Dynamics module. Both devices utilized the aforementioned real and reactive controls for this evaluation. Furthermore, CYME version 9.3 was required to sufficiently capture device control interactions with existing system devices as earlier versions displayed inaccurate voltage spikes upon device switching.

In this evaluation, native loading was determined for each hour across the annual hourly (8760) net loading data provided at each circuit. The native load, defined as net load plus aggregate generation/BESS outputs, was extracted to better understand each circuit's load profile. The existing hourly BESS data for the Feeder B circuit was also made available for this analysis.

The estimation of aggregate generation data per circuit was another crucial aspect of the analysis. Since individual generation profiles were not available for all PV units in the model, estimates were computed by multiplying each circuit's total nameplate generation by provided per-unitized regional PV outputs. This estimation method helped to account for local solar generation conditions and provided a more realistic view of the circuit's generation capability in lieu of individualized data.

PV generation outputs were scaled based on the loading scenarios, which were comprised of peak and light load 24-hour periods. For the peak load day, PV outputs were determined by multiplying the "RLC Volatile PV Profile" by the per-unitized regional PV outputs. The "RLC Volatile PV Profile" represents conservative PV volatility conditions across multiple sites (1 MW – 5 MW) in the Northeast region of the United States, derived from high resolution (1s – 5s) metering data. This profile is shown in Figure 4.

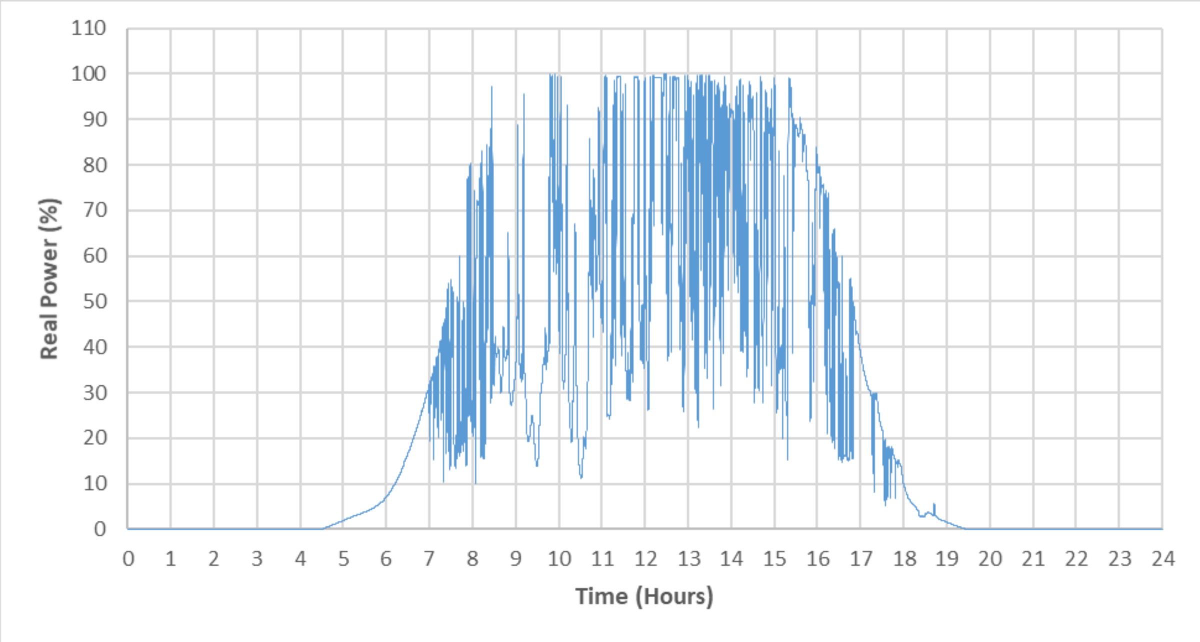


**Figure 4: RLC Volatile PV Profile**

For the minimum load day, PV outputs were calculated using a similar approach, but factored in the DER Scale %'s derived from steady state evaluations (see Table 3). This output was determined by the product of the "RLC Volatile PV Profile", the per-unitized regional PV outputs for the minimum load day, and the aforementioned DER scaling factors.

Lastly, the BESS outputs for the Feeder B circuit were scaled based on the metering data provided for peak and light load days. These outputs represented the existing BESS (Timed) operation; however, the BESS (Smart) control was based on the previously discussed operation of a 700 kW limit, thus allowing for eight (8) hours of continuous use when beginning simulations from a zero-charge state.

Time series simulations were conducted using the established load and generation profiles. 15-second simulation intervals were chosen based on empirical determination of required result granularity, which translated to 5,760 total load flow simulations per 24-hour period analyzed. Voltage (% of nominal), real power (kW), and reactive power (kVAR) were monitored at each applicable location with the purpose of observing device regulation capabilities under volatile DER conditions. Figure 5 displays time series plots for the Tie Controller + BESS (Smart) variant. These plots depict light load day conditions and parameters shown at both feeder heads and device interconnection locations.

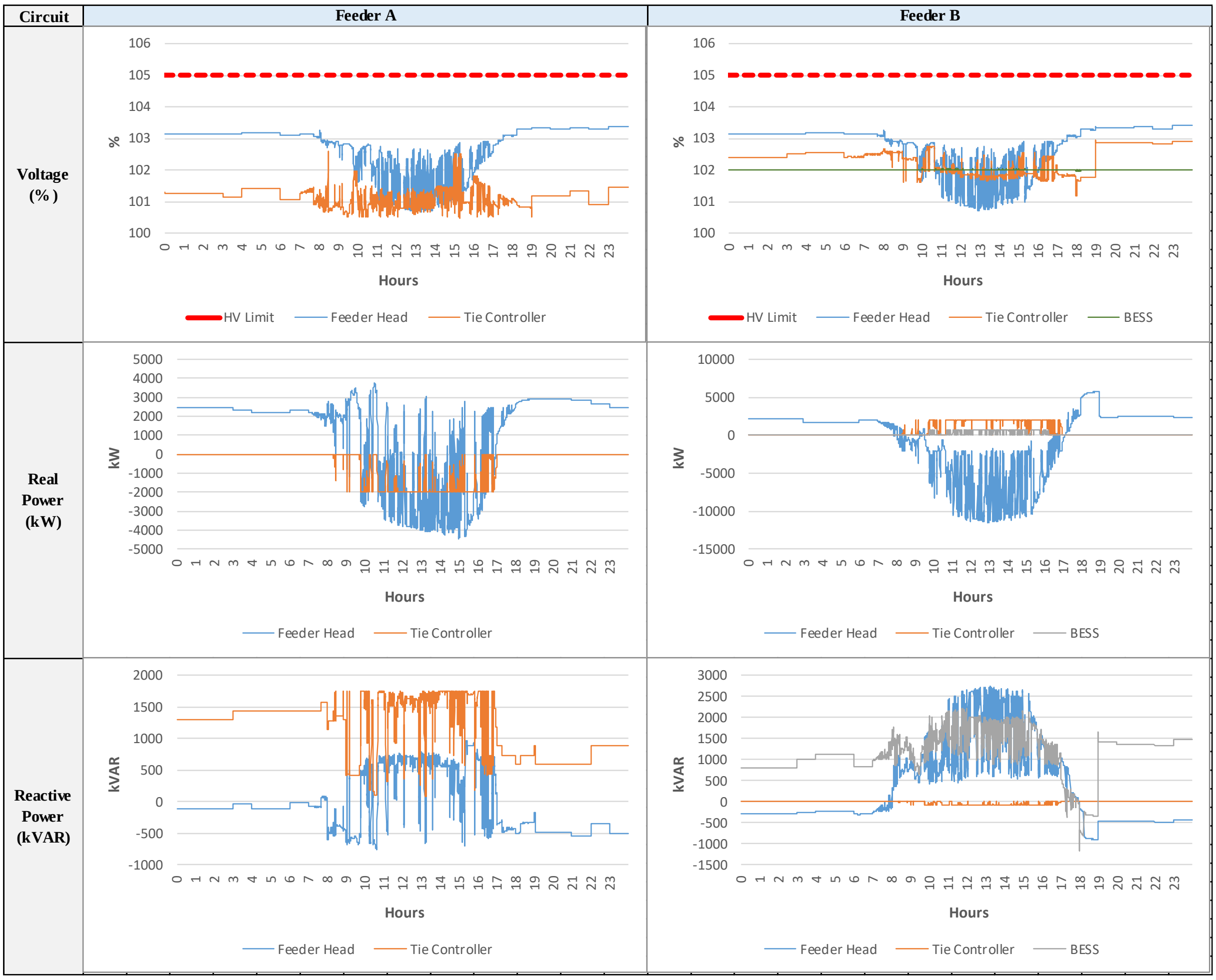


**Figure 5: Time Series Plots for Tie Controller + BESS (Smart) Variant During Light Load Day**

It can be seen that the Tie Controller + BESS (Smart) configuration allowed for observed voltages to remain within criteria despite the DER volatility following DER nameplate capacity increases of 6,345 kW on Feeder A and 8,446 kW on Feeder B (compared to the Existing System (BESS Off) variant, see Table 3). While the specific Tie Controller (TC-15k133) still experienced voltage fluctuations in some instances due to reaching its maximum output capacity (133 A), it can be seen that device outputs sufficiently followed DER profiles and minimized voltage fluctuations at the locations monitored. To further mitigate these fluctuations, a larger variant such as the TC-15k266 or TC-15k450 may be considered in the future to provide more transfer and regulation capacity to the system.

## Conclusions

The case study has showcased how adding the Tie Controller, smart control of the existing BESS, and combining the two can significantly improve the DER HC of the distribution system while maintaining grid criteria and ensuring reliability. As the study has demonstrated, the most impactful scenario is the combined usage of the Tie Controller and BESS (Smart) control variant, which resulted in a significant 477% increase in DER HC, corresponding to potential DER increases of 6,345 kW on Feeder A and 8,446 kW on Feeder B. This result could allow for a significantly higher penetration of renewable DER, thereby promoting a more sustainable and environmentally friendly power system.

The real-time voltage regulation capabilities of both the Tie Controller and BESS (Smart) control are noteworthy. This study confirmed their combined ability to dynamically respond to changes in DER output and load fluctuations by maintaining voltage levels within the acceptable range on both Feeder A (regulated by the Tie Controller) and Feeder B (regulated by the BESS), even under conservative light load, high DER volatility conditions. This aspect is crucial in the context of a grid with high penetration of intermittent renewable resources, such as PV, which may otherwise cause significant voltage fluctuations and potentially disrupt grid stability.

It is important to note, however, that this study was based on a specific distribution grid with particular characteristics. Therefore, it is recommended that similar studies be conducted in other distribution networks with different configurations and load profiles to validate these findings. As the power grid evolves and more DERs are integrated, further studies will be needed to assess and adapt these innovative solutions continuously.

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