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Georgia Power Pilot of Phase Balancing Technology

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SUMMARY

This paper presents the results of Georgia Power's pilot to evaluate Switched Source's Phase-EQ technology on a medium-voltage distribution circuit. Georgia Power served as the host utility for the project, with Switched Source providing the device and RLC Engineering serving as an independent consultant responsible for system simulations, evaluation, and siting. The Phase-EQ is a power electronics device designed to dynamically mitigate system imbalances by transferring power between phases, thereby reducing neutral current and correcting voltage imbalance. Such imbalances, commonly driven by seasonal load diversity, distributed energy resource (DER) integration, and long single- or two-phase laterals, are increasingly important considerations as utilities plan for more resilient and efficient distribution systems.

The Georgia Power pilot was structured to assess the Phase-EQ under real-world operating conditions and to validate simulation predictions with field data. A distribution circuit was identified as a candidate through screening based on high neutral current and voltage imbalance and was selected for installation after further site feasibility assessments. Once installed, the device was tested in both current control mode (targeting elimination of zero-sequence current) and voltage control mode (targeting elimination of zero-sequence voltage). While both modes are designed to mitigate imbalance, they employ different control objectives, offering an opportunity to compare their relative impacts on power quality.

A comprehensive set of simulations were performed prior to device deployment using Eaton's CYME power flow software that incorporated the device's specifications. These simulations predicted measurable improvements in both current and voltage imbalance and guided the siting decision to maximize device effectiveness. Following installation, field testing was carried out to observe device operation and to compare results against the modeled expectations. Key performance metrics included reduction in neutral current at the feeder head and at the device location, mitigation of voltage imbalance across the circuit, and overall improvements in upstream system balance.

This paper presents the results of these analyses, highlighting observed reductions in neutral current, improvements in voltage balance, and reasonable agreement between simulation and field performance. By validating the device's impact through real-world testing, the pilot provides practical evidence of how dynamic phase balancing can enhance system performance.

The findings contribute to the growing body of technical evidence surrounding advanced distribution system technologies, underscoring the Phase-EQ's ability to dynamically improve imbalance and power quality. These results offer Georgia Power and the industry insights into the operational performance of Phase-EQ technology under real world conditions.

KEYWORDS

Phase-EQ, Dynamic Phase Balancing, Power Quality, Non-Wires Alternative (NWA), Voltage Optimization

PILOT OVERVIEW

Georgia Power's pilot was designed to evaluate the real-world performance of Switched Source's Phase-EQ device on a medium voltage distribution feeder. This pilot follows earlier studies and pilots by other utilities and builds upon simulation-based analyses by focusing on how the device performs in live operation. Circuit A (real name redacted) was selected as the test site based on screening criteria that identified high neutral current and voltage imbalance, providing a meaningful environment in which to validate the technology.

The Phase-EQ was developed as a power electronics solution to one of the most persistent challenges in distribution system planning and operation: phase imbalance. Sources of imbalance are widespread and include uneven single-phase load growth, distributed energy resources (DER) connected at single-phase laterals, electric vehicle charging, and long feeder extensions [1, 2, 3, 4]. These conditions can result in excessive neutral current flow, elevated voltage imbalance, reduced efficiency, and accelerated wear on distribution equipment [1, 2]. The Phase-EQ addresses these challenges dynamically by continuously adjusting power flows between phases to reduce zero-sequence components.

Georgia Power's objective in this pilot was to determine whether the Phase-EQ could provide measurable benefits in practice and whether the device's operation aligned with expectations from prior modeling efforts. Specifically, the pilot was structured to:

- Assess the effectiveness of Phase-EQ operation in two distinct control modes: current control (zero-sequence current elimination) and voltage control (zero-sequence voltage elimination).
- Quantify changes in neutral current, voltage imbalance, and related power quality indicators at both the device and feeder head.
- Build internal knowledge of the device's capabilities and behavior under actual loading conditions.

To achieve these objectives, the project was divided into several stages. First, screening and siting activities were conducted to identify the most advantageous placement on Circuit A. Using Eaton's CYME power flow software, neutral current levels, voltage imbalance profiles, and circuit operating conditions were evaluated. The selected location was confirmed through field feasibility assessments, ensuring the device could be installed without major system modifications.

Following siting, the Phase-EQ was installed and commissioned. Field testing was then structured to capture device performance in both control modes. Measurements were taken at multiple locations, including the feeder head, nearby reclosers, and the device itself to allow for a comprehensive view of system impact.

This paper provides a detailed account of these efforts, beginning with a description of the device specifications, control modes, and power flow modeling approach, then presents the simulation results and siting process, followed by the results of both current control and voltage control operation in the field. The paper concludes with a summary of the Phase-EQ as demonstrated in this pilot.

PHASE-EQ SPECIFICATIONS

The Phase-EQ is a three-phase shunt-connected power electronics device designed for medium voltage distribution applications, up to 15 kV, and is rated for up to 133 A of neutral current. Its primary function is to mitigate system imbalance by dynamically transferring power among phases and can ramp to full power output in less than two cycles. The Phase-EQ's ability to reduce system imbalance can provide several power quality and operational benefits, including:

- Reduced neutral current flows upstream of the device
- Decreased current imbalance upstream of the device
- Reduced voltage imbalance across the circuit

These direct benefits can also support a number of secondary improvements, such as:

- Enhanced performance of conservation voltage reduction (CVR) schemes
- Improved inverter-based resource (IBR) voltage regulation
- More balanced operation of voltage regulators, increasing regulation capability
- Increased circuit capacity in the presence of phase imbalance
- Reduced operational expenditures (OpEx) from fewer rebalancing efforts and lateral re-tapping
- Mitigated imbalance from distributed energy resources (DER) and electric vehicle (EV) deployment
- Deferred need for costly upgrades such as reconductoring, line rebuilds, or three-phase extensions

The Phase-EQ is a pad-mounted device, with dimensions of approximately 4 feet 1 inch in width, 11 feet 9.5 inches in length, and 6 feet 0.25 inches in height, with a total weight of about 9,000 pounds. Figure 1 provides a summary of specifications and an image of an installed Phase-EQ.

Figure 1: Phase-EQ Specifications and Image

Phase-EQ Specifications	
Neutral Current Rating	133 A
Interconnection Voltage	15 kV 3-Phase
Power Rating at 15 kV	2 MVA
System Configuration	Wye, Wye-Grounded
100% Power Ramp	< 2 cycles
BIL Rating	95 kV
System Weight	~9,000 lbs
Operating Temperature	-40 °C to 50 °C
Enclosure	NEMA 4



PHASE-EQ CONTROL MODES

As discussed, the Phase-EQ is a three-phase, shunt-connected power electronics device that can be used to correct zero-sequence imbalance present on distribution systems. To achieve this corrective action, two control modes have been developed, described in detail below, that take advantage of the Phase-EQ's ability to inject zero-sequence current.

Current Control Mode

The primary objective of current control mode is to eliminate the zero-sequence current that arises due to the presence of imbalanced loading conditions. Through careful siting on the distribution line, the Phase-EQ can provide the aforementioned benefits by actively adjusting its injection so as to supply the zero-sequence current drawn by downstream loads.

In current control mode, this active injection adjustment is implemented via a closed-loop control scheme that takes as input the neutral current phasor (3x the magnitude of the zero-sequence current), measured using sensors mounted on the neutral conductor of a 4-wire wye-connected system. The deviation between the measured neutral current at the point of connection and the control reference, i.e., 0 A, is taken to be the error input of a proportional-integral (PI) controller. The output phasor of the PI controller is then taken as the command for the power electronics that comprise the Phase-EQ that drive its current injection.

When online and operating such that the baseline zero-sequence imbalance is mitigated, the PI controller continues to actively adjust the magnitude and angle of the current injected by the Phase-EQ in accordance with variations in imbalanced loads that are downstream of the measurement point. In this configuration, the amount of neutral current measured at the device is driven towards zero.

Voltage Control Mode

Given that the Phase-EQ is a current injector at its core, the most natural way to choose its output is based on a system current measurement, as is done in current control mode. However, it was observed during numerous field installations that there is often a tight coupling between the zero-sequence current and the zero-sequence voltage at the point at which the Phase-EQ is connected; therefore, a reduction in zero-sequence current sourced by the substation typically leads to a proportional reduction in zero-sequence voltage. Additionally, while current control mode has been shown to provide significant system benefits, it can only correct the imbalance that is downstream of the device, so it cannot correct imbalance caused by loads between the Phase-EQ and the substation.

To take advantage of the tight coupling between zero-sequence voltage and current that is typically observed, the voltage control mode was developed. In this control mode, the magnitude and angle of the current injected by the Phase-EQ is actively adjusted via an implementation of a closed-loop control scheme that takes the zero-sequence voltage of the line as an input. This zero-sequence voltage is computed by the Phase-EQ based on the phase voltage measurements taken internally by the device, thus obviating the need for any external sensors.

The deviation between the measured zero-sequence voltage and the control reference, i.e., 0 V, is taken to be the error input of a PI controller. The output phasor of the PI controller is then taken as the command for the zero-sequence current injected by the Phase-EQ. While the overall architecture of both control modes is very similar, it is important to note that the gains of the voltage control mode controller take different values and need to be tuned differently than those used when in current control mode.

When in voltage control mode, the Phase-EQ can correct imbalance that results from loads both upstream and downstream of the point of interconnection, thus potentially having broader impacts than a device in Current Control Mode. Furthermore, eliminating the dependence on an external current sensor can simplify the installation and, importantly, can afford significant flexibility when siting the device.

PHASE-EQ MODELING IN CYME

An off-the-shelf representation of the Phase-EQ is not available in CYME. To enable simulation studies, a custom model was developed that combined single-phase battery energy storage system (BESS) components with CYME's Python-based device control scripting.

The modeling architecture functioned as follows:

- CYME passed system conditions (voltages and currents) to Switched Source's device control model through the Python interface.
- Switched Source's control model processed these inputs and determined the appropriate operating response of the Phase-EQ device.
- The resulting real and reactive power setpoints were returned to the single-phase BESS components, which represented the Phase-EQ's power injection on each phase within CYME.

This modeling framework replicates the operation of the Phase-EQ device, allowing for detailed simulation of how it responds to varying feeder conditions. By leveraging this approach, the study compared simulation results with field data, validating both the device's performance and the accuracy of the modeling representation.

SIMULATION RESULTS & DEVICE SITING

Georgia Power identified four distribution circuits with known imbalance as potential candidates for Phase-EQ deployment. These circuits were screened using historical operational data and engineering judgment to highlight locations with phase imbalance, neutral current, and voltage imbalance. A comparative evaluation was then performed using CYME to determine the circuit best suited for demonstrating Phase-EQ operation. Key screening metrics included:

- Neutral Current – Circuits with higher neutral current were prioritized, as the Phase-EQ is designed to reduce these currents.
- Voltage Imbalance – Phase-to-phase voltage unbalance was considered due to its impact on customer equipment and feeder power quality.
- Load Distribution – The mix of single-phase and three-phase loads was reviewed to identify where the device could most effectively redistribute power.

The device siting process used:

- Heat Map Analyses – Visualizations of neutral current and voltage imbalance to target areas of highest impact.
- Distance from Substation – Sites close to the source were deprioritized, since voltage imbalance reduction is less impactful near the substation.
- Feasibility – Practical factors such as pad space, accessibility, and infrastructure compatibility.

Based on the simulated performance in CYME, Circuit A was selected for the pilot. Figure 2 illustrates the heat map results (prior to adding the device) that were generated for Circuit A and highlights the installation site that was selected. This location exhibited both elevated neutral current (≈132 A) and voltage imbalance, providing the greatest opportunity for measurable benefits.

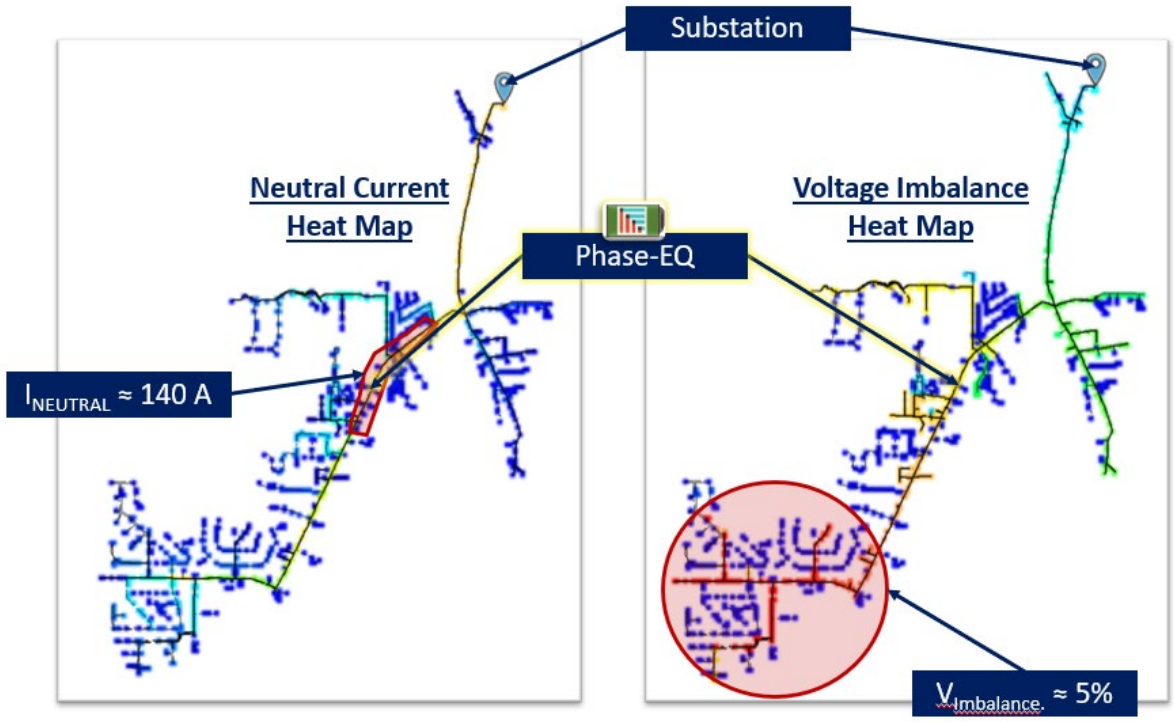


Figure 2: Heat Map Results for Circuit A (Before Phase-EQ)

Based upon a historic peak load snapshot, the following system benefits were observed in simulation after the addition of the Phase-EQ in current control mode:

- Feeder head neutral current was reduced from 123.8 A to 14.1 A, a 109 A reduction.
- Upstream meter neutral current was reduced from 156.5 A to 46.2 A, a 110 A reduction.
- Local neutral current, measured at the device, was reduced from 132.4 A to 0.1 A, a 132.3 A reduction.
- The maximum feeder voltage imbalance was reduced from 5.39% to 2.63%, a 2.76% reduction, effectively reducing the maximum voltage imbalance by half.

Additionally, a critical load evaluation was performed in CYME by uniformly scaling system loads until a voltage or thermal limit was reached. This assessment was repeated with and without the Phase-EQ to quantify potential capacity benefits. Table 2 summarizes the results.

Table 2: Summary of Capacity Benefits

Status	Voltage Critical Load Level				Thermal Critical Load Level			
	%-Peak Load Scale	3Ø Power (kW)	$I_{NEUTRAL}$ (A)	Max $V_{imbal.}$ (%)	%-Peak Load Scale	3Ø Power (kW)	$I_{NEUTRAL}$ (A)	Max $V_{imbal.}$ (%)
Off	112.5%	7,917	142.1	6.4%	117.0%	8,247	149.0	6.8%
On	112.5%	7,919	7.2	3.4%	126.0%	8,907	25.1	4.1%
Change (On - Off)	0.0%	2	-134.9	-3.0%	9.0%	660	-123.9	-2.6%

The following observations were made:

- Voltage Limit: The Phase-EQ improved imbalance metrics but did not increase the voltage-limited critical load. Without the Phase-EQ, A-Ph and C-Ph were heavily loaded, and experienced voltages near 95%. The device shifted B-Ph load to C-Ph, which reduced neutral current and voltage imbalance; however, the heavy A-Ph loading remained a limiting factor.
- Thermal Limit: The device increased the thermal critical load by 9% (660 kW), by reducing the most heavily loaded phase.

FIELD TEST RESULTS

Field testing began in late May 2025 with the Phase-EQ operating in voltage control mode and continued until mid-July. During this period, several on vs. off assessments were conducted to quantify device performance. In mid-July, the unit was switched to current control mode to establish comparative benefits against voltage control. At the time of writing (late August 2025), the device has remained in current control mode, with additional on vs. off testing performed.

Data was collected from four meters, though this paper focuses on three: the feeder head, an upstream midline meter located a few spans upstream of the device, and a downstream meter approximately one span downstream of the device. The Phase-EQ also records internal measurements, but the upstream and downstream meters provided sufficient data due to their proximity to the device. Field data were logged at 10-minute intervals over the three-month test period, providing a robust dataset.

To enable a consistent comparison, three peak load snapshots were selected:

- Phase-EQ off (baseline), 7/27/2025 at 17:17
- Phase-EQ on, voltage control mode, 6/25/2025 at 17:29
- Phase-EQ on, current control mode, 7/20/2025 at 17:54

These snapshots were selected because they occurred under nearly identical loading conditions, enabling a good comparison of device impact. Table 3 summarizes system loading at both the feeder head and the downstream meter for the three conditions. Note that because the Phase-EQ is shunt-connected, the downstream meter's individual phase current readings are largely unaffected by the device's operation. As a result, the downstream meter serves as a reliable reference point for system loading, providing a clear basis for comparing conditions independent of the device.

Table 3: System Loading Comparison at Feeder Head and Downstream Reference Point

Status / Time	Feeder Head	Downstream Meter				
	Apparent Power (kVA)	A-Ph Current (A)	B-Ph Current (A)	C-Ph Current (A)	Neutral Current (A)	Apparent Power (kVA)
Phase-EQ Off 7/27/2025 17:17	6,905	262	143	300	144	5,026
Voltage Control 6/25/2025 17:29	6,959	265	146	296	145	5,078
Current Control 7/20/2025 17:54	6,865	263	144	294	145	5,030

As shown, feeder head apparent power across the snapshots was within 100 kVA (~1.4%), with the downstream meter showing a similarly tight ~1.0% variation. This confirms comparability of conditions for evaluating device performance. Table 4 summarizes the observed benefits of the Phase-EQ under these peak load conditions.

Table 4: Summary of Device Benefits under Peak Load Conditions

Status	Feeder Head			Upstream Meter			Downstream Meter		
	In (A)	Iimbal. (%)	Vimbal (%)	In (A)	Iimbal. (%)	Vimbal (%)	In (A)	Iimbal. (%)	Vimbal (%)
Device Off	121.0	21.8	0.6	145.0	38.1	3.7	144.0	39.1	3.7
Voltage Mode	19.0	11.6	0.1	48.0	23.6	2.5	145.0	38.0	2.6
Current Mode	32.0	12.5	0.1	60.0	25.6	2.3	145.0	38.4	2.6
Voltage Mode Reduction	-102.0	-10.1	-0.5	-97.0	-14.5	-1.2	N/A*	N/A*	-1.1
Current Mode Reduction	-89.0	-9.3	-0.4	-85.0	-12.5	-1.4	N/A*	N/A*	-1.1

The comparison of peak loading conditions demonstrates that both voltage and current control modes significantly reduce system imbalance. At the feeder head and upstream midline meter, neutral current and current imbalance decreased substantially, while voltage imbalance also improved. As expected for a shunt-connected device, the downstream meter showed little change in current imbalance but did reflect improvements in voltage imbalance. Although field results confirmed notable reductions in neutral current – particularly at the upstream meter – the magnitude did not perfectly match the 110 A reduction observed in simulation. This discrepancy reflects differences between simulated system conditions, which were based on historic load measurements, and the field-tested system conditions. Overall, voltage control mode delivered slightly stronger performance at this site.

To illustrate device behavior across a broader range of operating conditions, scatter plots were generated comparing imbalance metrics to load. Because imbalance is inherently load-dependent, these plots provide a clearer view of device effectiveness than isolated snapshots.

- At the feeder head, Figures 3 and 4 show reductions in neutral current and current imbalance with the Phase-EQ online. Voltage imbalance was not plotted due to limited sensitivity so close to the source.
- At the upstream midline meter, Figures 5–7 show reductions across all three metrics (neutral current, current imbalance, and voltage imbalance), again with voltage control mode providing the strongest performance.

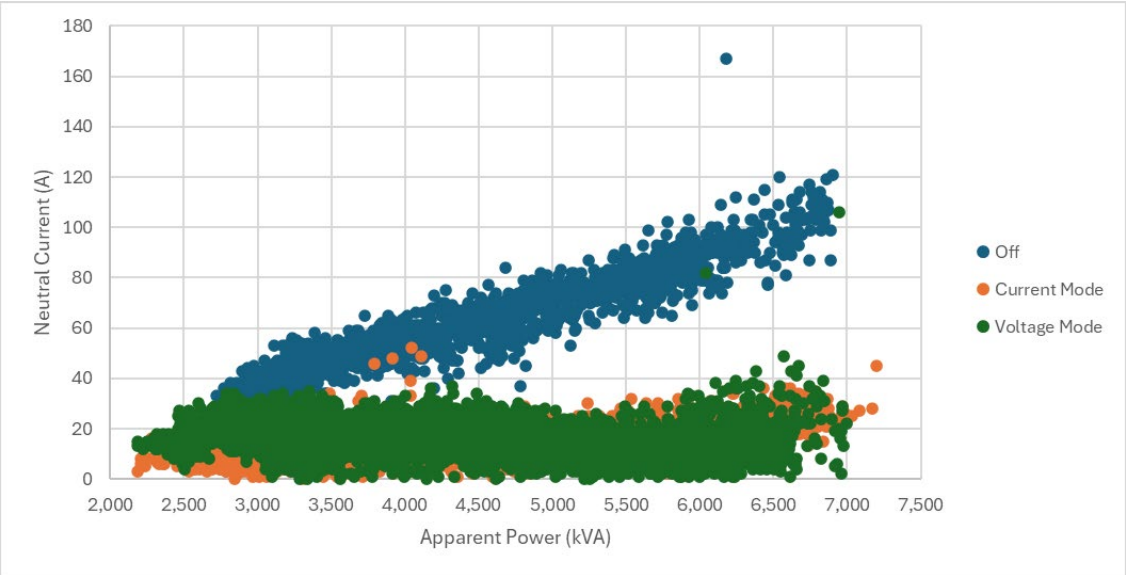


Figure 3: Feeder Head, Neutral Current Plot

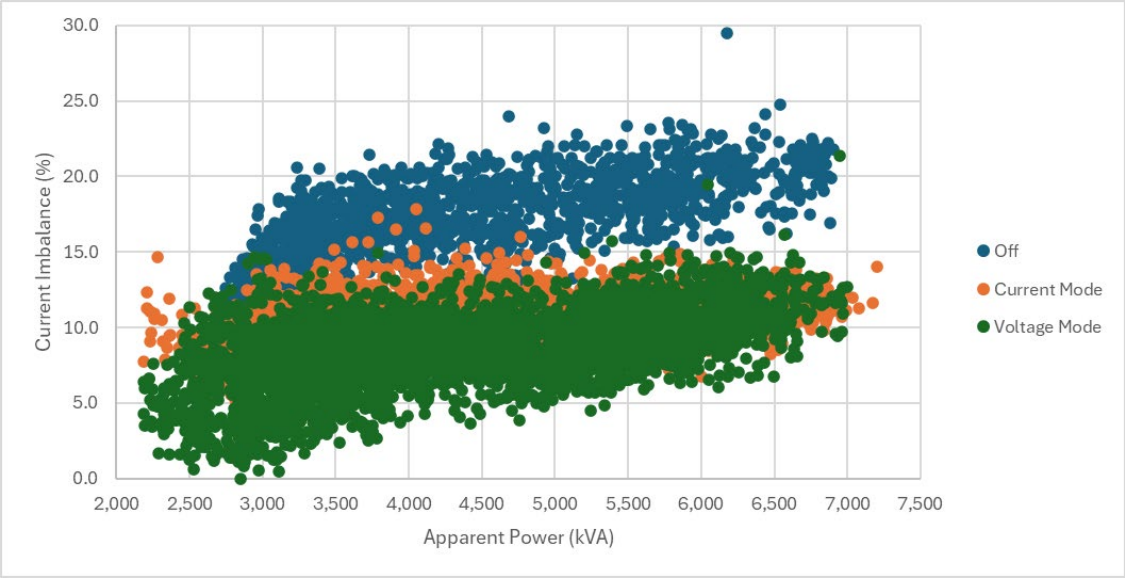


Figure 4: Feeder Head, Current Imbalance Plot

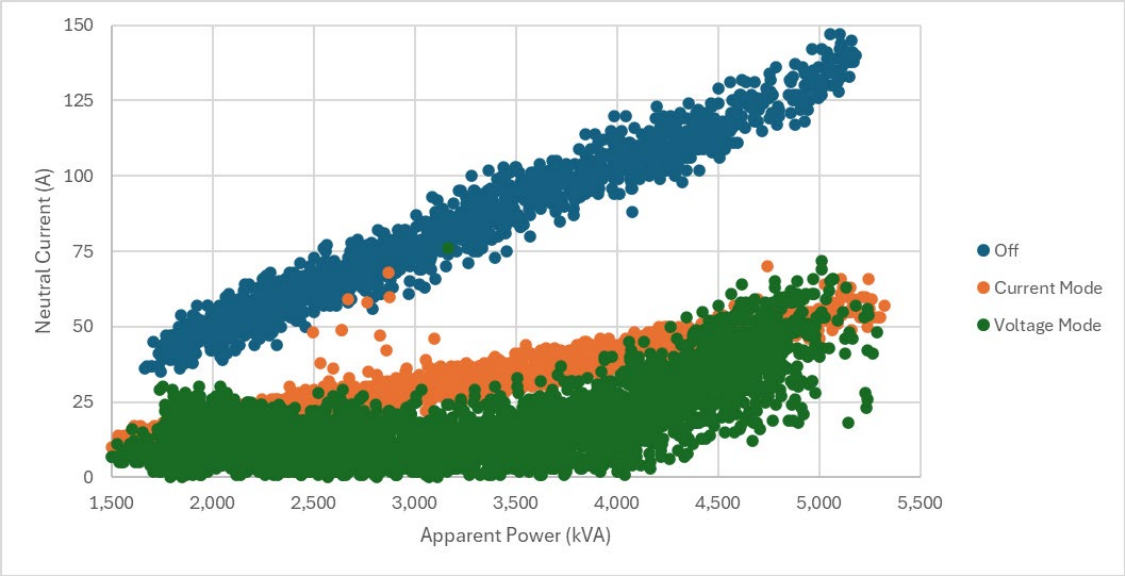


Figure 5: Upstream Midline Meter, Neutral Current Plot

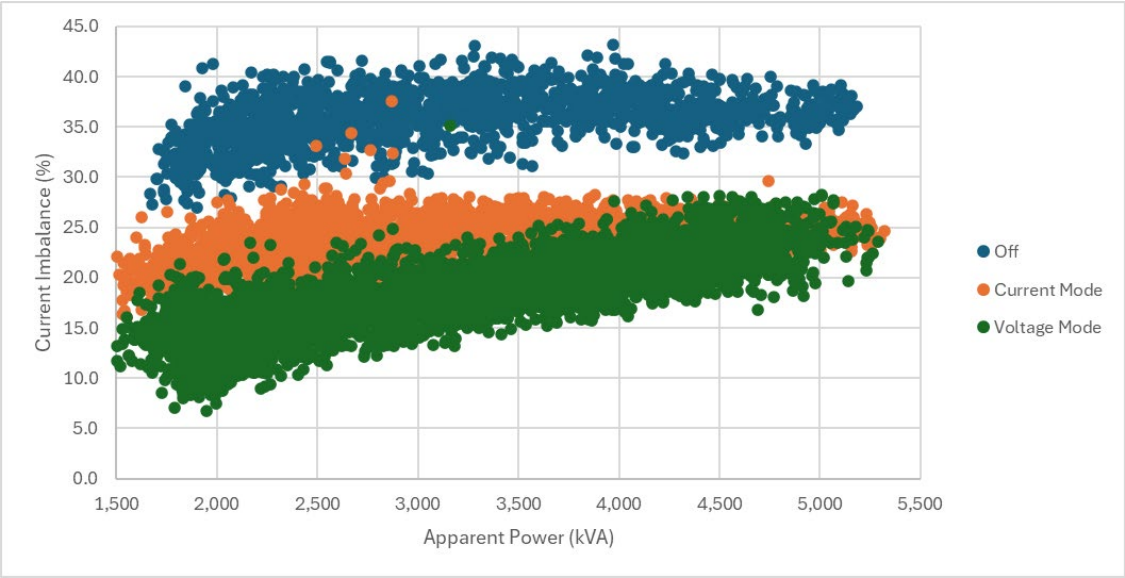


Figure 6: Upstream Midline Meter, Current Imbalance Plot

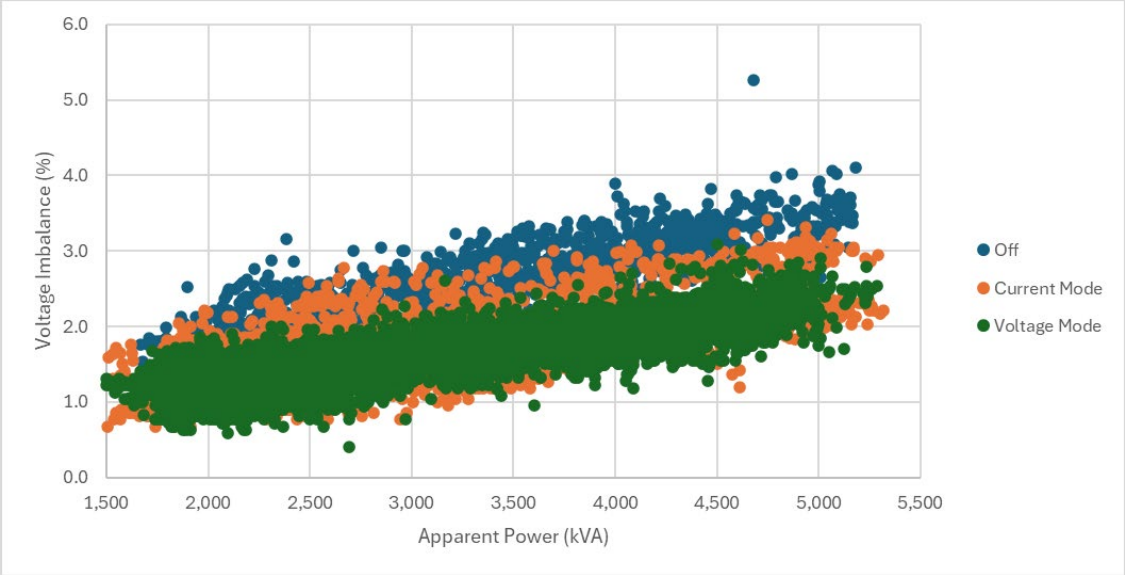


Figure 7: Upstream Midline Meter, Voltage Imbalance Plot

CONCLUSION

The Georgia Power Phase-EQ pilot demonstrated that dynamic phase balancing can deliver measurable improvements in distribution system performance under real-world operating conditions. Both current control and voltage control modes significantly reduced neutral current, current imbalance, and voltage imbalance at multiple monitoring points on Circuit A. Voltage control mode provided slightly stronger overall performance, particularly in mitigating upstream imbalance.

The pilot confirmed that the Phase-EQ consistently reduced system imbalance in the field, validating both the device's intended functionality and the general accuracy of the modeling approach. While field measurements did not precisely replicate the magnitude of reductions predicted in simulation – reflecting natural differences between historic load assumptions and actual operating conditions – the results nonetheless demonstrated substantial improvements in neutral current and voltage imbalance. These reductions support the expectation that the device can provide meaningful thermal capacity relief under practical conditions. By dynamically addressing imbalance, the Phase-EQ offers utilities a flexible, non-wires alternative (NWA) for improving power quality, supporting conservation voltage reduction (CVR), accommodating growing DER and EV penetration, and extending the useful life of

existing assets. The results of this pilot contribute valuable evidence to the industry and provide Georgia Power with practical insight into how advanced distribution technologies can be integrated to build more resilient and efficient power systems.

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