PVSizer: An Open-Source Python Framework for PV and BESS Sizing in Distribution Networks

Project Lead: Yilu Liu (UTK) and Fran Li (UTK)	
Research Specialist: Yayu(Andy) Yang (UTK)	
Project Duration: 10/2024 – 10/2025	
Funding Source: Department of Energy (DOE)	

Summary

PVSizer is a newly developed open-source Python framework designed to optimize the sizing of Photovoltaic (PV) systems and Battery Energy Storage Systems (BESS) within distribution networks. While originally motivated by the deployment of renewables on underutilized land such as retired landfills, the tool is versatile enough for preliminary sizing at any site. The primary objective is to maximize PV capacity while minimizing BESS requirements, ensuring that all local grid limits and stability constraints are maintained.

The framework is structured into three distinct analysis modules to cater to different planning needs:

- **Traversal/Feasibility map:** Tests all PV–BESS capacity combinations to map feasible operating regions.(Parallel Computing Architecture)
- **Quick solution:** Utilizes a hill-climbing algorithm to find the optimal PV and BESS sizes that meet all grid constraints.
- **Single test run:** Evaluate the impact of a specified-size PV and a specified-size BESS on the microgrid using 24-hour time series simulation.

The optimization logic focuses on maximizing the **PV rated active power** while determining the **minimum required BESS rated active power**.

To ensure grid reliability, the framework monitors several critical constraints: Power Flow Convergence; Voltage Limits; Thermal/ Loading Limits; Battery Capacity Constraints.

The effectiveness of PVSizer was demonstrated using a **Knoxville Utilities Board (KUB)** distribution feeder model. The tool successfully identified the feasibility frontier, mapping out where loading violations occur and where battery oversizing becomes unnecessary.

PVSizer is a newly developed PV and BESS design tool that maximizes PV size while minimizing BESS requirements within distribution system limits. It provides a tool for utilities, planners, and researchers to perform rigorous PV–BESS integration studies.

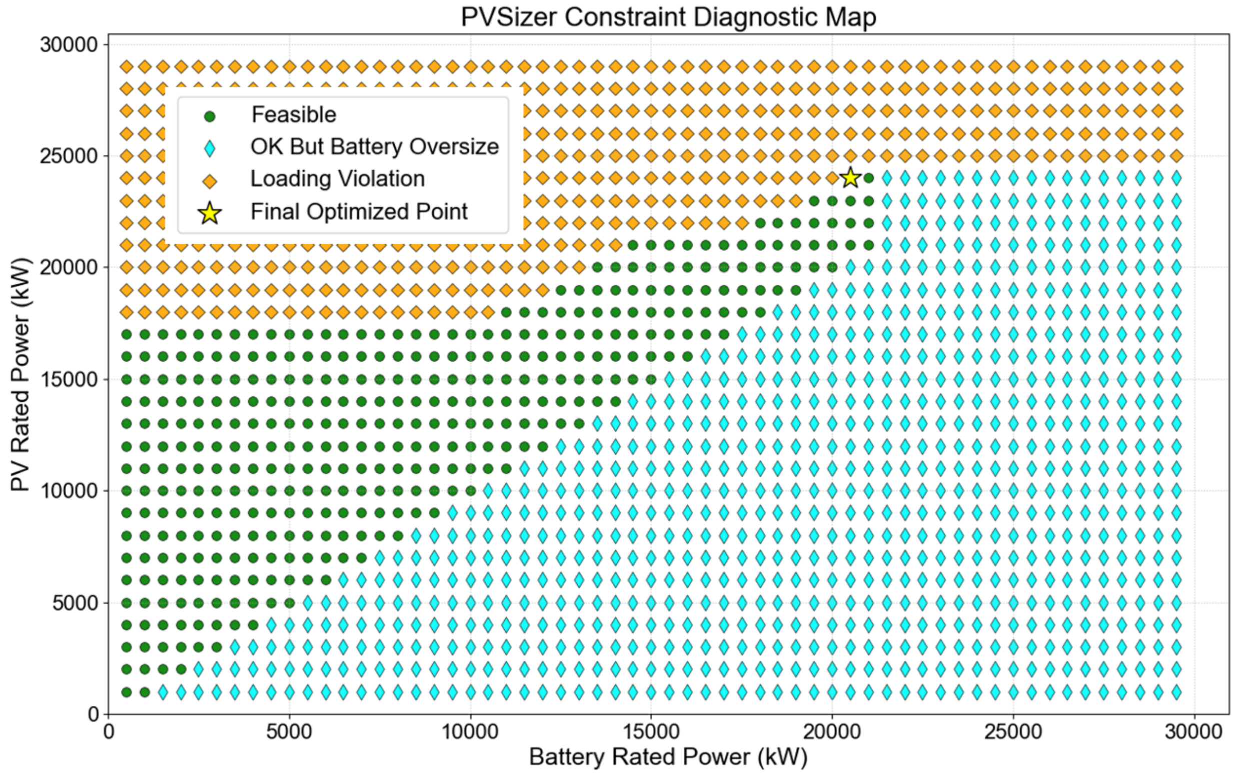


Figure 1: Traversal/Feasibility map results

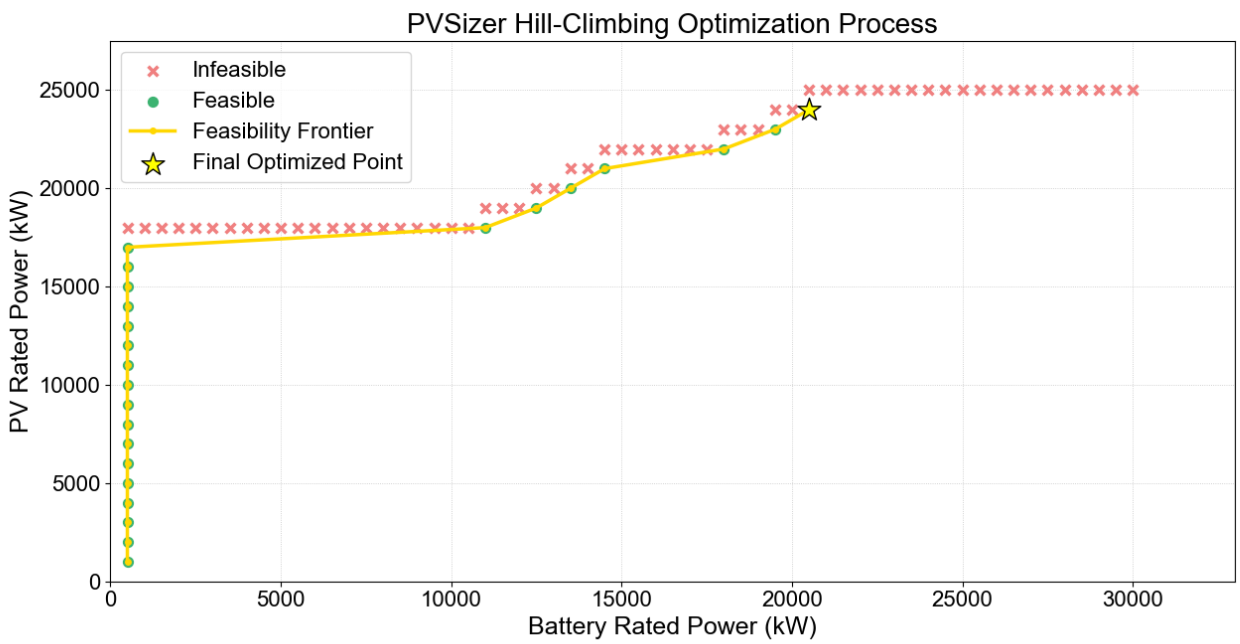


Figure 2: Quick solution results

Measurement-informed Dynamic Aggregation of Distribution Systems

Project Lead: Yilu Liu (UTK), Jin Dong (ORNL) **Graduate Students and Research faculty/associates:** Kazi Ishrak Ahmed (UTK), Yuru Wu (ORNL)	
Project Duration: 01/2024 – 12/2027	
Funding Source: Department of Energy (DOE)	

Summary

With the increasing penetration of distributed energy resources (DERs), such as solar photovoltaics, battery systems, and inverter-based loads, accurately representing their dynamic behavior has become essential for transmission system analysis. However, detailed modeling of distribution-level DERs is often impractical due to data limitations and computational complexity.

This project, led by the UTK and ORNL team as part of the MOON project, develops an aggregated dynamic modeling framework to provide a medium-resolution representation of DER behavior. The approach leverages measurement data to estimate aggregated dynamic parameters, enabling accurate modeling of system responses to disturbances while maintaining computational efficiency.

The model is designed for compatibility with large-scale transmission studies, including WECC 240-bus and utility-scale systems, ensuring practical applicability. By bridging the gap between detailed distribution modeling and transmission-level analysis, this work supports improved stability assessment, situational awareness, and operational decision-making for grid operators.

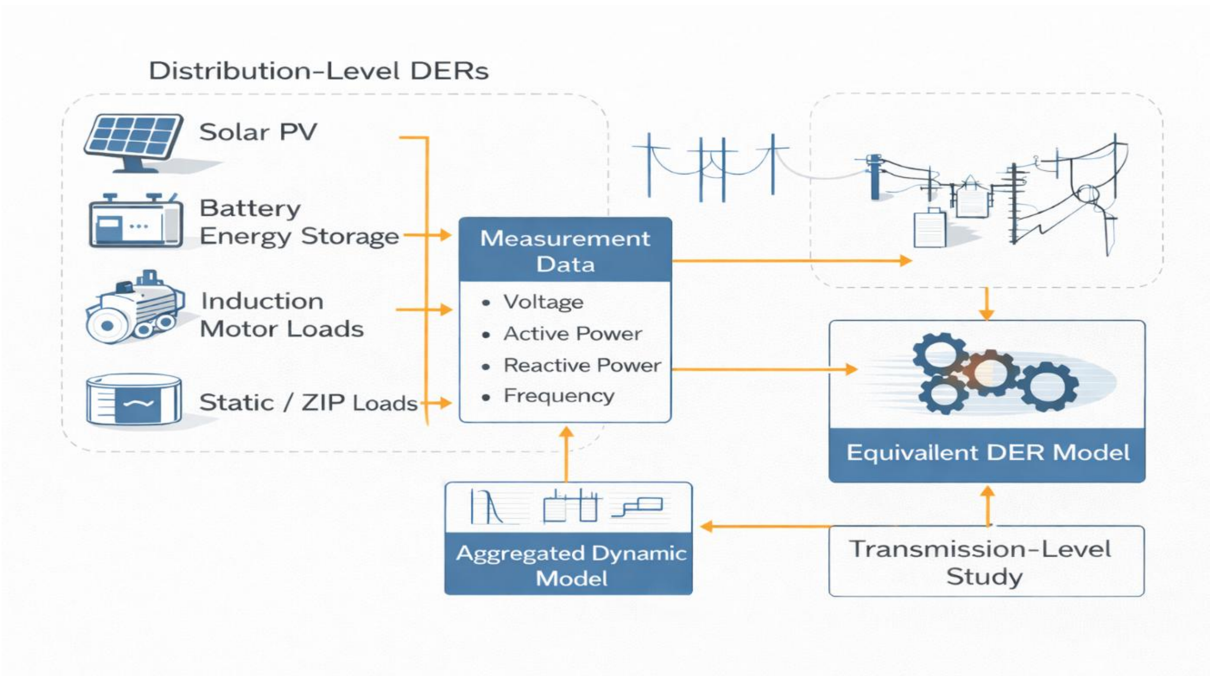


Figure 1: Dynamic Load Modeling Framework

Acoustic UAV Detection at Electrical Power Substations Using a Harmonic Signature Tracking Method

Project Lead: Yilu Liu(UTK) **Graduate Students and Research faculty/associates:** Chong Shen (UTK), Yayu Yang (UTK), Jin Dong (ORNL), Ali Boyaci (ORNL), Ali Ekti (ORNL), Yuru Wu (ORNL)
Project Duration: 11/2025 – 3/2027
Funding Source: DOE

Summary

The rapid proliferation of unmanned aerial vehicles (UAVs) has introduced increasing security concerns for critical power infrastructure, particularly electrical substations. Unauthorized UAV activities near substations may lead to risks such as equipment surveillance, physical intrusion, and potential disruption of grid operations. Ensuring reliable detection of UAVs in such environments is therefore essential for improving situational awareness and infrastructure protection. To address this challenge, this project develops a robust and practical acoustic-based UAV detection framework, referred to as the Harmonic Signature Tracking Method. This approach leverages the distinctive harmonic sound patterns generated by UAV propellers and provides a cost-effective alternative to more complex sensing modalities.

The proposed method integrates three key components: signal preprocessing, harmonic feature extraction, and temporal voting. First, raw acoustic signals are enhanced using preprocessing techniques such as high-pass filtering and noise reduction to suppress environmental interference and improve signal clarity. Next, the enhanced signal is analyzed in short time windows to identify harmonic structures characteristic of UAV operation. Finally, a temporal voting mechanism is applied to ensure that detected harmonic patterns remain consistent over time, thereby improving detection reliability and reducing false alarms. Unlike machine learning-based approaches, this framework does not require large labeled datasets or computationally intensive training, making it well-suited for real-time implementation and deployment on resource-constrained edge devices.

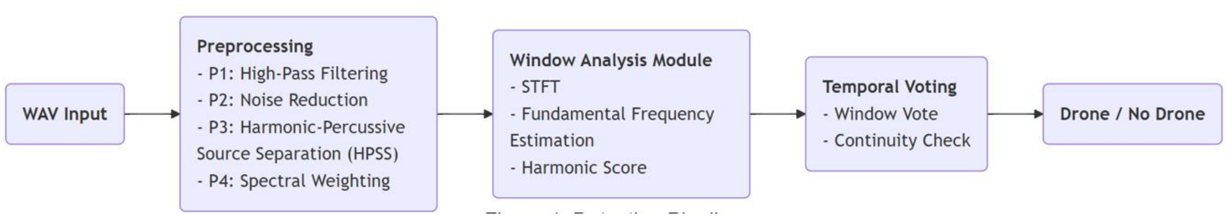


Figure 1: The architecture

To evaluate the effectiveness of the proposed approach, a realistic acoustic dataset was constructed under substation-relevant conditions. Due to safety and regulatory constraints, UAV recordings were collected in an open outdoor environment using a DJI Mavic platform at distances ranging from 0 to 50 meters in 5-meter increments, with approximately one minute of data recorded at each distance. In parallel, background noise recordings were obtained near an operational electrical substation to capture representative environmental interference. These datasets were then combined to preserve realistic propagation characteristics of UAV sounds while incorporating complex substation noise, providing a challenging and practical test scenario for algorithm evaluation.

Figure 2: Experiment Setup

Experimental results demonstrate that the proposed method achieves strong detection performance under noisy conditions. Specifically, a low false alarm rate of 4.48% was observed on background-noise-only data, indicating high robustness against non-UAV acoustic interference. Additionally, reliable detection of the DJI Mavic platform was achieved at distances of up to 25 meters. These results highlight the feasibility of using a lightweight, harmonic-based acoustic detection framework for practical UAV monitoring in substation environments. Ongoing work focuses on extending the detection range and further optimizing the system for real-time deployment on edge computing platforms, with the goal of enhancing both the security and operational awareness of modern power systems.

Development of Load Flexibility Valuation Methodology & Framework to Input into System Planning Tools

Project Lead: Fran Li (UTK) **Graduate Students and Research faculty/associates:** Jingzi Liu (UTK), Chenchen Li (UTK)	
Project Duration: 10/2023 – 9/2024	
Funding Source: Southern Company (SOCO)	

Summary

This project aims to develop a framework for assessing load flexibility and energy sustainability. The primary objective is to accurately predict the potential utilization of flexible loads in the future by analyzing energy load shapes and data related to energy usage. Additionally, this framework aims to facilitate energy savings. Ultimately, the intrinsic value that load flexibility offers to the grid will be adequately captured in this project. In this context, the incentive-based demand response (I-DR) mechanism has gained significant attention by utilizing financial incentives to encourage participation in demand reduction activities on a voluntary basis. Participants can decide whether to reduce load based on accepting or rejecting financial incentives. As such, an I-DR capacity assessment tool is developed to analyze the flexibility of residential loads within the territory of Southern Company (SOCO).

The framework of the I-DR capacity assessment tool is shown in Fig. 1. Given that potential measurement issues may appear in the field data, a data preprocessing module is implemented as the initial step to convert field data into a format suitable for assessment. Subsequently, the core module for I-DR capacity assessment is designed to quantify variations in residential demand behaviors and the corresponding financial incentives required. Finally, to enhance interpretability and decision-making, a visualization module is designed to provide a comprehensive representation of the I-DR potential capacity in the residential service territory, guiding demand elasticity through three-dimensional (3D) figures and statistical lists.

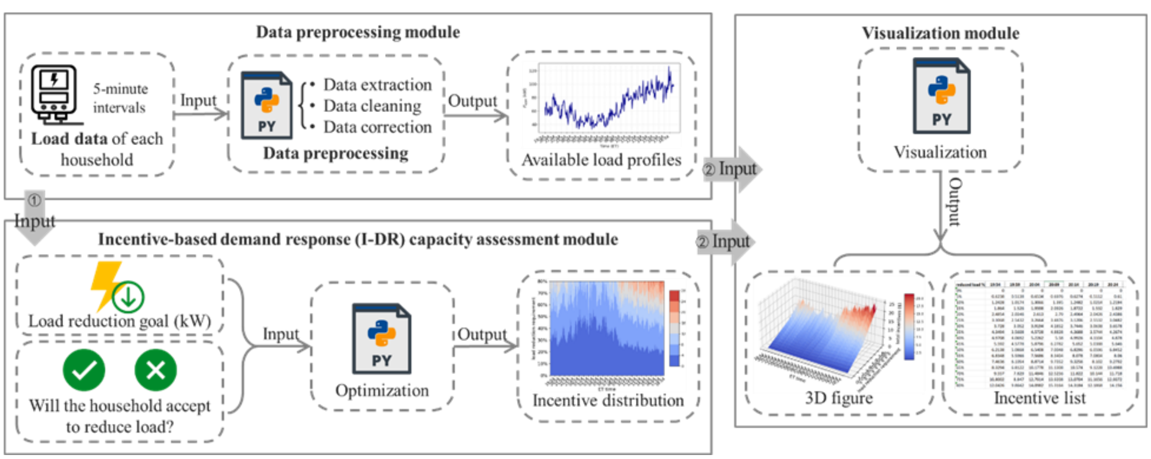
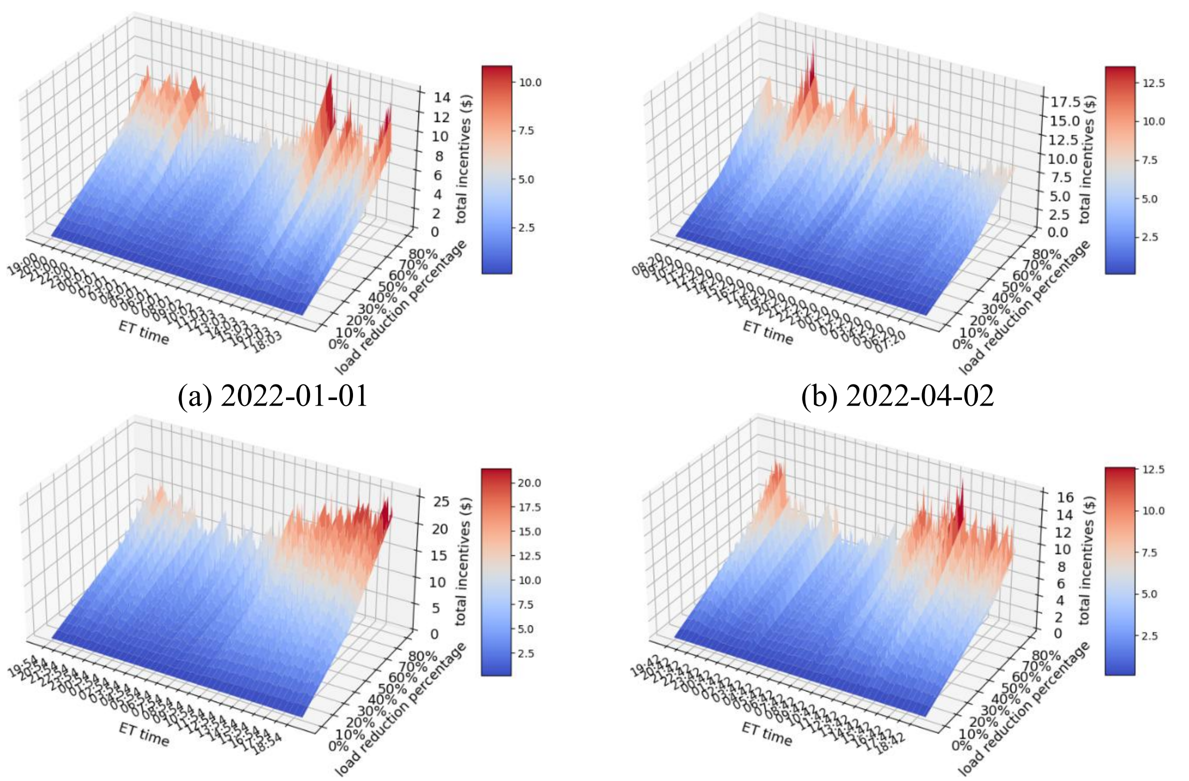


Figure 1: The framework of I-DR capacity assessment tool

The first module, the data preprocessing module, comprises a data extraction script to extract discrete field load data, a statistics-based data cleaning method to remove outliers caused by potential measurement issues, and a DNN-based adaptive data correction method to correct identified outliers, ensuring compatibility with subsequent assessments. The second module includes an optimization model designed to minimize the financial incentives paid to households within the service territory for participating in load reduction. The individual energy consumption preferences of each household are incorporated as constraints. After receiving a load reduction goal, households can decide whether to participate in reducing load. Based on their decisions, variable financial incentives are applied to encourage participation. The final module provides a 3D figure to visualize variations in household energy consumption behaviors with the minimum required financial incentives under different timestamps. Additionally, an incentive list is provided to facilitate a straightforward review of specific financial incentives based on the load reduction amount at a given timestamp. Finally, the generated incentive list is formatted as an Excel file. As shown in Fig. 2, SOCO field data from four randomly selected days, one from each season, are used to generate 3D visualization.



(a) 2022-01-01 (b) 2022-04-02

(c) 2022-07-20 (d) 2022-10-11

Figure 2: 3D figures of the total minimum financial incentives required by households within the SOCO service territory to meet load reduction goals

This tool provides a precise evaluation of the potential for utilizing flexible loads, thereby enhancing the efficient allocation and management of energy resources, which contributes to energy and environmental sustainability. Such residential capacities are instrumental in advancing decarbonization and promoting energy sustainability. Additionally, by quantifying energy elasticity, this tool offers utility companies deeper insights into the regulation of their generation and load, fostering better energy sustainability within the service territory.

Enhanced Online Oscillation Detection Framework for Sub-Synchronous Oscillation (SSO)

Project Lead: Yilu Liu (UTK) **Graduate Students and Research faculty/associates:** Hao Fu (UTK), Yan Wen (UTK), Wenpeng Yu (UTK), Lin Zhu (EPRI)
Project Duration: 11/2025 – 11/2026
Funding Source: EPRI

Summary

This project presents improvements to the online oscillation detection framework in the Forced Oscillation Localization Tool (FOLT) to support sub-synchronous oscillation (SSO) scenarios. Compared to conventional forced oscillations, SSO events are shorter in duration, higher in sampling rate, and more localized, requiring substantial adaptation of the original detection logic.

To support SSO testing, the data streaming module was updated to handle high-framerate, short-duration datasets and to include frequency measurements alongside voltage and current channels. Early issues with unstable triggering were traced to residual buffered data and timing inconsistencies. These were resolved by introducing explicit timing resets and a quiet initialization period between streaming cycles, significantly improving stability and repeatability.

At the framework level, the original forced-oscillation-oriented detection adapter was modified to better accommodate SSO characteristics. The updated structure strengthens the integration between data streaming, detection, and visualization components, enabling more consistent online detection performance.

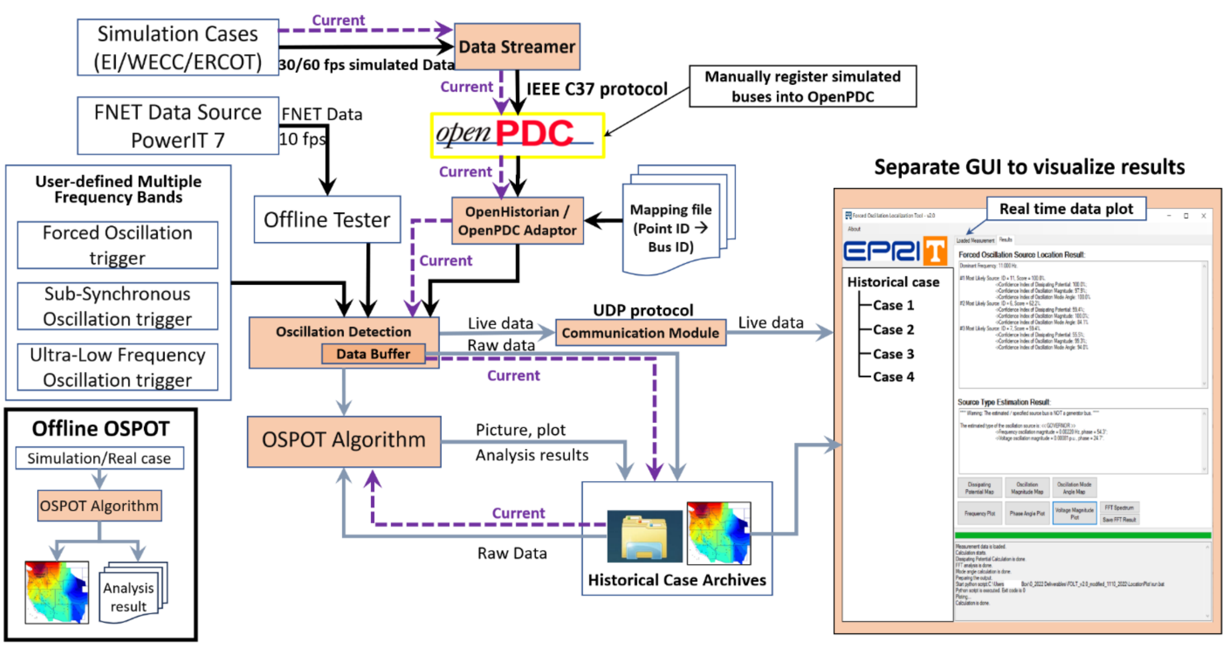


Figure 1: Updated online oscillation detection framework with SSO-oriented enhancements.

Detection logic at the individual measurement level was refined to better capture short-lived and localized oscillations. Envelope updating was accelerated, and conservative rejection conditions designed for long-duration events were relaxed. These changes allow the system to detect transient oscillatory behavior without prematurely discarding valid signals.

Frequency-domain processing was also improved to better align with SSO characteristics. Ultra-low-frequency components are excluded, and magnitude-based filtering thresholds were relaxed to preserve weaker oscillatory signatures. These adjustments enhance the reliability of dominant frequency identification and reduce missed detections.

To address the short duration of SSO events, the analysis time window was redefined to align closely with the detected oscillation interval. Early transient portions are excluded, and the window length is reduced to focus on the most informative segment of the signal. This ensures consistency between online detection and offline analysis.

Event lifecycle management was further refined to improve responsiveness. The updated logic enables faster confirmation and termination of oscillation events, reducing unnecessary computation and preventing interference from residual data.

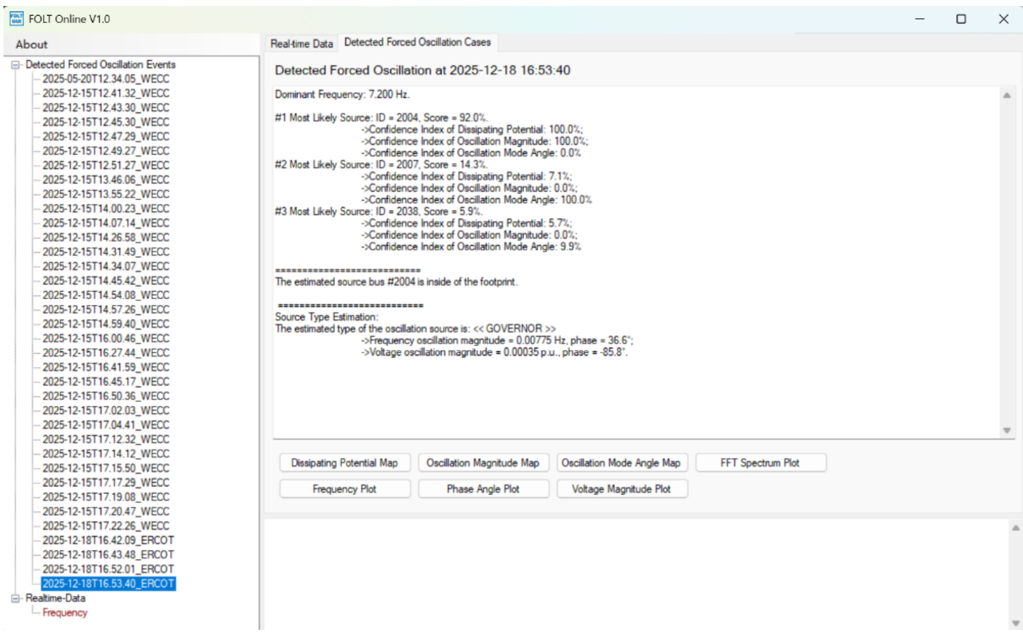


Figure 3: Example of online GUI output for sub-synchronous oscillation detection.

Finally, improvements were made to ensure consistency between simulation-based testing and online deployment. These include stricter control of timing, alignment of frame rates, and consistent inclusion of frequency measurements across datasets. Together, these enhancements provide a stable and reliable framework for detecting and analyzing sub-synchronous oscillations in real time.

Wide-Area Oscillation Damping Control Using FACTS as Actuators: TERNA Case Study

Project Lead: Yilu Liu (UTK) **Graduate Students and Research faculty/associates:** Haozong Wang (UTK)
Project Duration: 2/2025 – 12/2025
Funding Source: Terna Energy

Summary

Low-frequency inter-area oscillations remain an important operational concern in large interconnected power systems, including the European grid. To address this issue, this work investigates a wide-area damping control (WADC) approach that uses phasor measurement unit (PMU) signals as controller inputs and Flexible AC Transmission System (FACTS) devices as actuators. The study focuses on two actuator types: STATCOMs and FACTS resistors. The controller is based on a lead-lag compensation structure, and its effectiveness is evaluated through both simulation studies and field validation. The results indicate that both actuator types are capable of providing effective oscillation damping in practical transmission-system applications.

The developed WADC framework employs the sophisticated lead-lag compensation control and then adapted to different actuator technologies, as shown in Figure 1. For STATCOM, the actuator is represented in PSS®E using the CSTCNT model, and the damping control command is injected into the voltage-reference setpoint. For FACTS resistor, the actuator is represented using REGCA1 and REECDU1 models, and the damping command can be applied through active-power and reactive-power references separately or simultaneously.

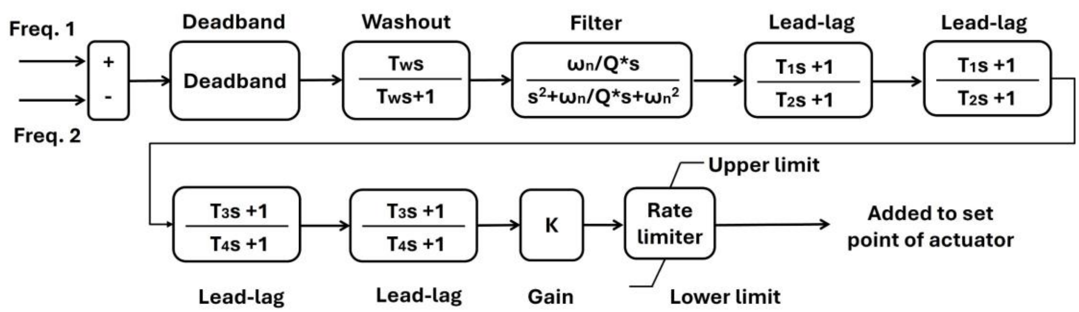
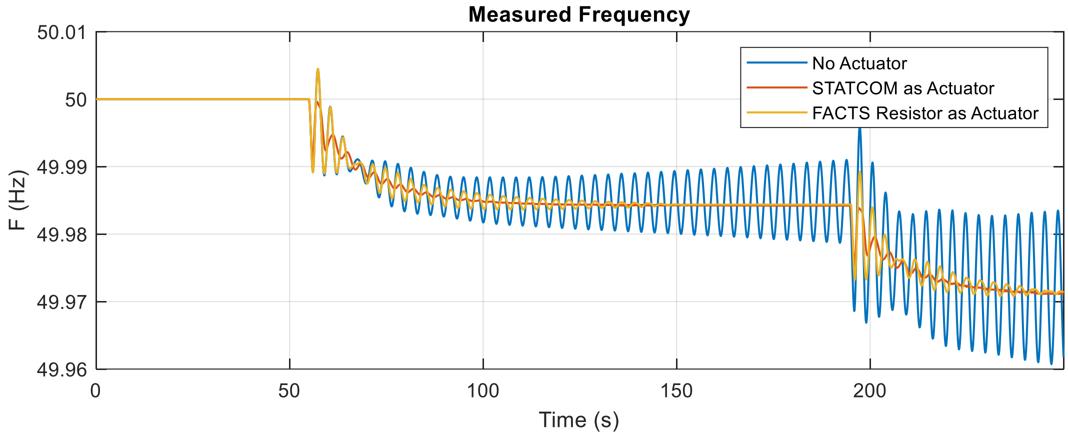
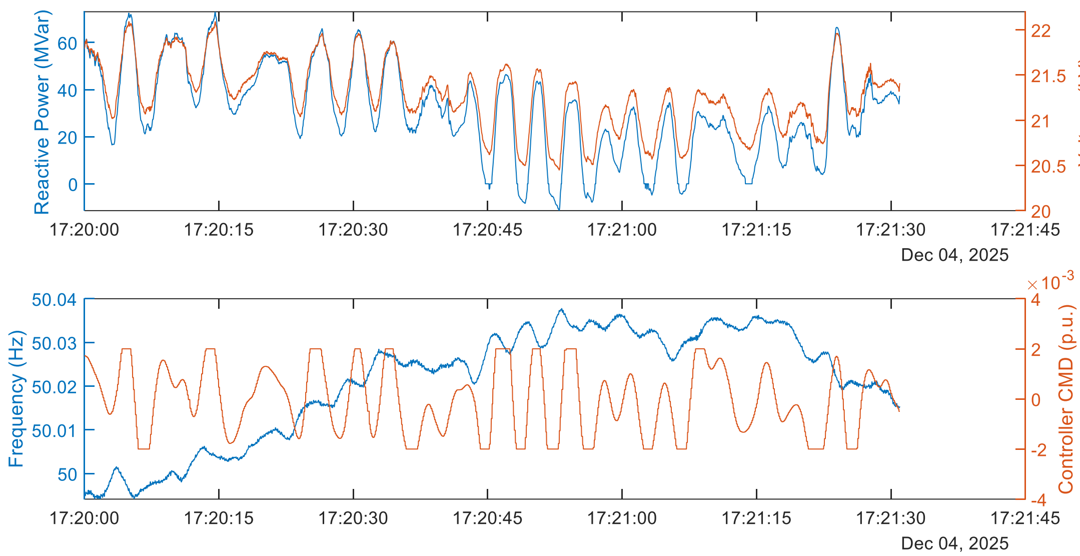


Figure 1: Controller Diagram

A broad set of simulation studies was conducted to assess the influence of actuator capacity, installation location, number of devices, available control margin, and operational constraints. For FACTS resistors, the comparison also included different control channels, especially active-power and reactive-power modulation. The simulation results show that both STATCOMs and FACTS resistors are feasible WADC actuators, and that increasing total actuator capacity generally improves damping performance. Among the tested FACTS resistor control strategies, active-power control typically provides better damping performance than reactive-power control in the studied scenarios. In contrast, actuator location has a relatively smaller influence on the overall damping effectiveness. The results also highlight that practical deployment constraints, such as output saturation and ramp-rate limits, must be considered when designing and tuning wide-area damping controllers. Field validation further confirms the practicality of the proposed approach. For STATCOM-based damping control, both open-loop and closed-loop tests were carried out, and the closed-loop test demonstrated measurable improvement in oscillation damping. In particular, the damping ratio of a 0.28 Hz mode increased from 7% to 9%, verifying that STATCOMs can effectively serve as actuators for wide-area oscillation damping in a real grid environment. The representative results of simulations and field tests are shown in Figure 2.



(a) Representative Simulation Results



(b) Closed-Loop Field Test Results

Figure 2: Representative Results of WADC using FACTS as Actuators

This study shows that both STATCOMs and FACTS resistors are promising actuator candidates for PMU-based WADC. While STATCOM field tests have already demonstrated the concept, field testing of FACTS resistors is expected in the next phase, which will further validate their practical applicability and provide additional guidance for large-scale deployment.

Frequency Response of Windowed DFT Phasor Estimation: Impact on Oscillation Observability

Project Lead: Yilu Liu (UTK / ORNL) **Graduate Students and Research faculty/associates:** Jiahui Yang (UTK), Yuru Wu (UTK/ORNL), Haozong Wang (UTK), Yu Liu (UTK), Biao Sun (UTK), Clifton Black (Southern Company Services)
Project Duration: 2026.1-now
Funding Source: UTK

Summary

The growing penetration of inverter-based resources (IBRs) in modern power systems has introduced sub-synchronous oscillations spanning 0.1–30 Hz, which can degrade equipment and, in severe cases, precipitate system-wide blackouts. Phasor Measurement Units (PMUs) are widely deployed for oscillation monitoring, and most PMU outputs are produced through windowed Discrete Fourier Transform (DFT) based phasor estimation. The window length required by IEEE Standard C37.118.1—short for P-class, long for M-class—fundamentally shapes the frequency response of the estimator and, consequently, how faithfully oscillation components are preserved in the reported phasor stream. Under certain conditions, these windowing effects can distort reported oscillation magnitude and phase, or suppress oscillation components entirely, yielding PMU data that appears quiescent even when the underlying grid is actively oscillating.

This project derives the complete complex-valued frequency response of the windowed DFT phasor estimator under both magnitude and phase modulation of the input signal. The two modulation models are:

$$x[p] = \sqrt{2}V_{\mathrm{rms}}(1 + \alpha \sin(\Omega_m p + \varphi_{\mathrm{m}})) \cos(\omega_0 p + \varphi_0) \quad (1)$$

$$x[p] = \sqrt{2}V_{\mathrm{rms}} \cos(\omega_0 p + \varphi_0 + \beta \sin(\Omega_m p + \varphi_m)) \quad (2)$$

Propagating each through an L-point windowed DFT yields closed-form expressions for the resulting phasor. The analytical result is the frequency-dependent complex gain

$$H_1(e^{j\lambda}) = \frac{\sqrt{2}}{L} e^{j\lambda(L-1)/2} \cdot \frac{\sin(L\lambda/2)}{\sin(\lambda/2)} \quad (3)$$

whose magnitude and phase,

$$G = |H_1(e^{j\Omega_m})|, \;\; \theta = \angle H_1(e^{j\Omega_m}) \quad (4)$$

govern the attenuation and phase shift imposed on any oscillation component. Because this gain is known in closed form, the true oscillation amplitude and phase can be recovered from measured PMU data using

$$A_{\mathrm{rec}} = \sqrt{2} \cdot \frac{A_{\mathrm{meas}}}{G}, \;\; \varphi_{\mathrm{rec}} = \varphi_{\mathrm{meas}} - \theta \quad (5)$$

provided the oscillation frequency does not coincide with a comb-null of the response. The magnitude and phase of the complex gain are plotted in Figure 1 for window lengths parameterized by h = 1, 2, 4, 8 (corresponding to increasingly long DFT windows).

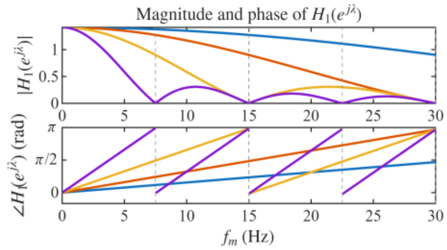


Figure 1: Magnitude and phase of the complex gain H_1

Figure 2 presents the time-domain case study that validates the analytical model. Synthetic signals with magnitude modulation (α = 0.010) or phase modulation (β = 0.020 rad) at controlled modulation frequencies are passed through the windowed DFT phasor estimator, and the V_{mag} and V_{ang} streams are calculated for h = 1, 2, 4, 8. Subfigure (a) — a slow 0.1 Hz magnitude modulation — shows all four window lengths producing nearly overlapping ±1% envelopes with negligible attenuation, confirming that low-frequency oscillations are preserved regardless of PMU class. Subfigure (b), magnitude modulation at f_m = 15 Hz, is the critical comb-null case: the analytical gain G predicts exact zeros for h = 4 and h = 8, and the h = 4 and h = 8 traces collapse to a flat 1.0 RMS line in the plot, completely suppressing a real oscillation that is still present in the input. Only the h = 1 and h = 2 traces retain visible oscillation, though already attenuated relative to the true ±1% amplitude. Subfigure (c), magnitude modulation at f_m = 20 Hz, exhibits the progressive-attenuation regime: the h = 1 trace reproduces the full ±1% amplitude, h = 2 shows moderate attenuation, h = 4 is noticeably smaller, and h = 8 is reduced to roughly one-tenth of the true amplitude — a quantitative match to the G values read from Figure 1 at 20 Hz. Subfigure (d), phase modulation at the same f_m = 20 Hz, shows the identical attenuation pattern in V_{ang} together with clearly offset zero-crossings between the four h values, confirming the analytically predicted phase shift θ. Together the four cases demonstrate that (5) yields faithful calculation of both amplitude and phase whenever f_m avoids a comb-null.

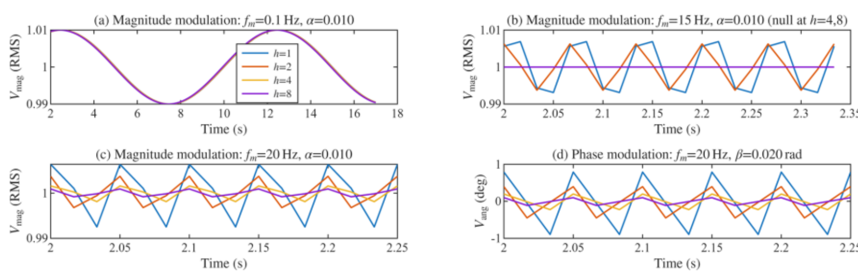


Figure 2: Time-domain case study of reconstructed phasors for h = 1, 2, 4, 8. (a) Magnitude modulation at f_m = 0.1 Hz; (b) magnitude modulation at f_m = 15 Hz (comb-null at h = 4, 8); (c) magnitude modulation at f_m = 20 Hz; (d) phase modulation at f_m= 20 Hz.

The practical implications for utility oscillation monitoring are significant. The windowed DFT introduces both frequency-dependent magnitude attenuation and phase shift to oscillation components, so detected oscillation magnitudes may systematically underestimate true severity, and the absence of oscillations in phasor data does not guarantee oscillation-free operation—oscillations may be canceled at comb-null frequencies or heavily attenuated well below detection thresholds. For sub-synchronous oscillation monitoring driven by IBR proliferation, shorter DFT windows (P-class configurations) are preferable because they push comb-nulls well outside the frequency band of interest and flatten the passband; an anti-aliasing filter upstream of the estimator is additionally recommended to suppress image components. Beyond monitoring, the recovery formula (5) enables direct reconstruction of true oscillation amplitude and phase from existing PMU archives whenever f_m is known or can be identified via spectral analysis.

OEDI – Solar Grid Integration Data and Analytics Library

Project Lead: Yilu Liu (UTK) **Graduate Students and Research faculty/associates:** Yayu Yang (UTK), Haozong Wang (UTK), Hao Fu (UTK), Zhengfa Zhang (UTK), Jin Dong (ORNL), Boming Liu (ORNL)	
Project Duration: 9/2021 – 9/2026	
Funding Source: DOE	

Summary

As the integration of distributed energy resources (DERs) into distribution systems accelerates, existing models are increasingly unable to meet emerging R&D needs due to proprietary constraints, limited data quality, and the absence of high-DER scenarios, time-series data, and transient representations. Moreover, the lack of standardized tools for algorithm testing and benchmarking restricts reproducibility and hinders practical adoption. At the same time, the growing penetration of EVs, energy storage, and flexible loads introduces faster system dynamics and greater operational complexity, demanding more advanced modeling and analytical capabilities.

This project aims to develop an open-source distribution system modeling and data platform tailored for high solar penetration. The main tasks include: (1) developing representative models with high DER integration and enriched datasets; (2) enabling key use cases such as demand-side management and dynamic EV charging through modular data processing frameworks; (3) establishing open interfaces and benchmarking tools to support algorithm validation and comparison; and (4) creating a transient event library and associated analysis tools to capture critical phenomena such as faults, harmonics, and oscillations.

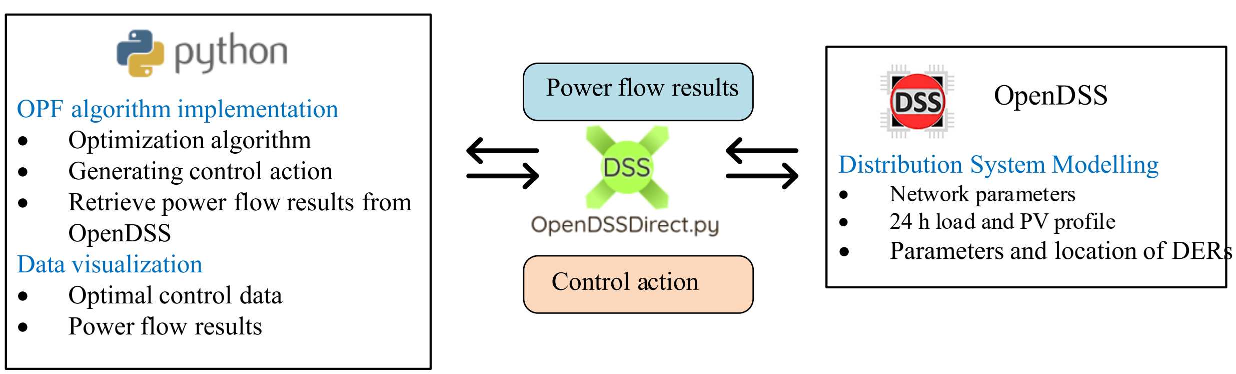


Figure 1: Hybrid D-OPF Framework

Real-Time Local Damping of Wideband Power Oscillations Using Droop-Controlled IBRs

Project Lead: Yilu Liu (UTK) **Graduate Students and Research faculty/associates:** Saurav Dulal (UTK)
Project Duration: 10/2025-10/2026
Funding Source: ORNL/DOE

Summary

This project develops a real-time local damping strategy for inverter-based resources (IBRs) to mitigate wideband power oscillations in modern power systems. As IBR deployment increases, oscillatory modes can vary in frequency, severity, and location, while conventional power oscillation damping schemes often rely on fixed tuning or centralized coordination. The proposed approach instead uses the fast-response capability of droop-controlled IBRs to provide decentralized damping based on local measurements. By activating only when sustained oscillations are detected and by adapting control parameters online, the framework is intended to improve responsiveness, scalability, and practical deployability in inverter-dominated grids.

The control architecture, shown in Fig. 1, combines local measurement and buffering, continuous modal analysis, envelope-based triggering, phase compensation, and mode-aware droop control. Frequency deviations measured at the IBR terminal are stored in a rolling window and processed using a modal analysis method such as fast Fourier transform to identify the dominant oscillation mode. Once the oscillation envelope exceeds a predefined threshold, the controller computes phase compensation parameters T1 and T2 and assigns a gain K according to the detected mode characteristics, for example using a residue-based gain selection strategy. This enables rapid delivery of an appropriately phased damping signal through active or reactive power modulation.

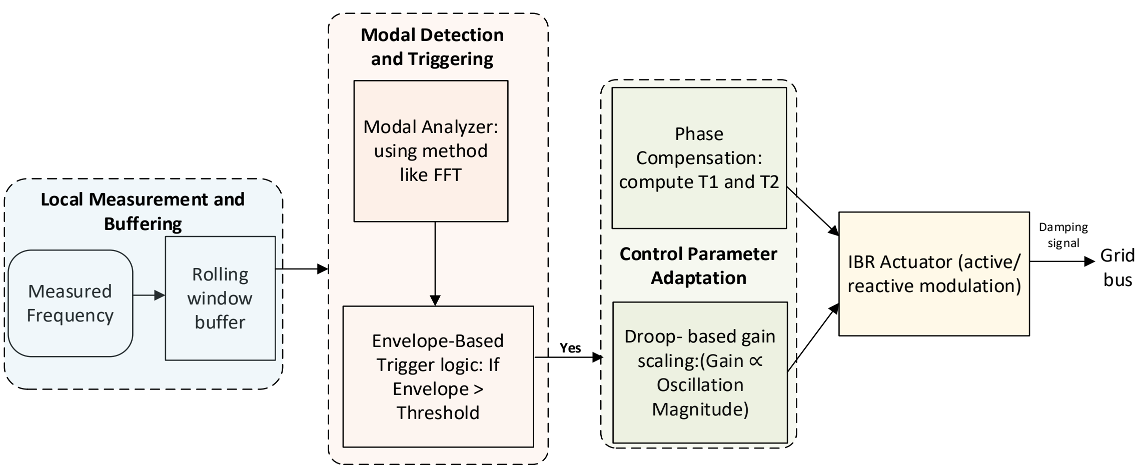


Figure 1: Real-time local control architecture with envelope-based triggering and mode-aware droop-modulated damping via IBRs.

Implementation is envisioned in the ERCOT synthetic power system using Python and PSS/E co-simulation. Small-signal oscillations can be introduced through low-amplitude sinusoidal perturbations at generator mechanical power or external signal functions, allowing the controller to be evaluated across a broad oscillation range. Because measurement, detection, and gain adaptation are performed locally, the framework can be deployed in a modular manner across multiple IBRs without requiring centralized coordination. This structure also supports continuous background updating so that control action can be applied with minimal latency once a trigger condition is satisfied.

Compared with conventional IBR-based damping schemes tuned for fixed modes, the proposed framework is designed to deliver frequency-aware and severity-aware damping over a wide operating band. The project therefore establishes a practical foundation for adaptive oscillation mitigation in future low-inertia systems, with potential benefits for small-signal stability, operational flexibility, and scalable integration of inverter-based controls. The resulting methodology can support subsequent testing, controller tuning, and broader evaluation of decentralized damping strategies in realistic transmission system environments. A preliminary conceptual result is as shown in Fig. 2.

Table 1: Summary of the proposed adaptive damping workflow

Module	**Role in the framework**
Local measurement and buffering	Collect local frequency deviations and maintain a rolling data window for real-time analysis.
Modal detection and triggering	Use FFT-based spectral analysis and envelope logic to identify sustained oscillations and activate control only when needed.
Control parameter adaptation	Compute phase compensation terms T1 and T2 and assign a mode-aware gain K based on the detected oscillation characteristics.
IBR actuation	Inject active or reactive power modulation through the IBR interface to provide appropriately phased damping.

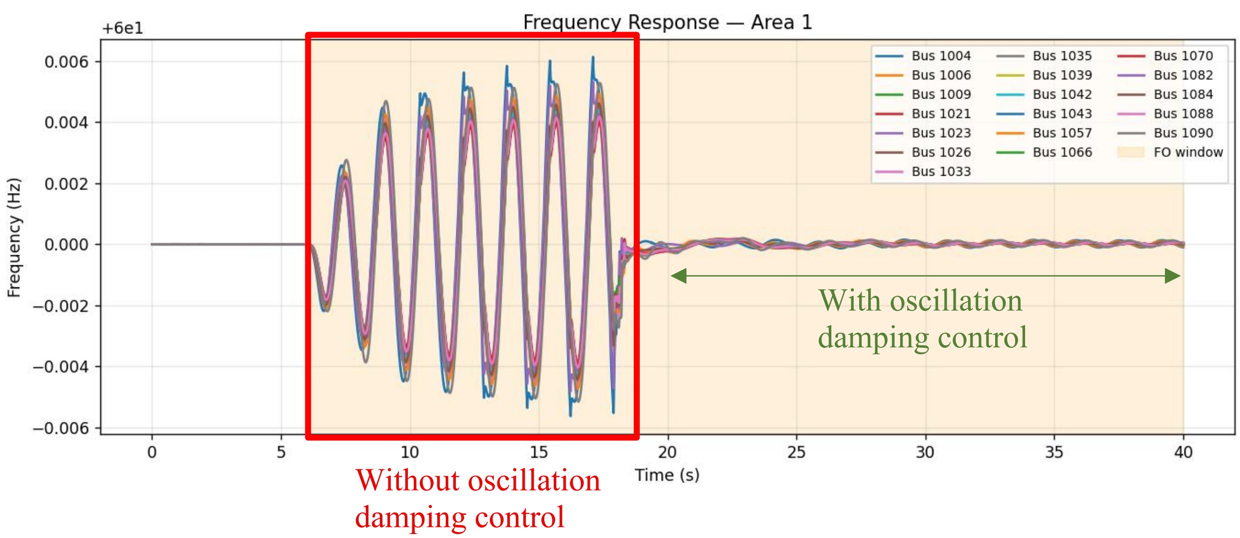


Figure 2: Oscillation damping Control vs no control.

Large-Scale Data Center Load Modeling With Real Event Scenario

Project Lead: Dr. Yilu Liu (UTK), Amirreza Sahami (Dominion Energy) **Graduate Students and Research faculty/associates:** Stephanie Tomasik (UTK), Xinlan Jia (UTK)
Project Duration: 2024 – Present
Funding Source: Dominion Energy

Summary

This project investigates how large-scale data center loads can be more accurately represented in bulk power system dynamic simulations. As data center development accelerates across the United States, these loads are becoming large enough to noticeably affect voltage and frequency behavior during major disturbances. Conventional static load representations are often not sufficient to capture the fast and voltage-sensitive response of data center loads. The goal of this work is to improve how these emerging loads are modeled so planners can better evaluate their impact on system reliability and stability.

To address this need, the project applies the composite load model (CMLD) in PSS®E to represent large-scale data center behavior in an Eastern Interconnection planning case. A real disturbance event from July 10, 2024, involving a permanent 230 kV line fault, followed by six reclosing attempts, and the transfer of approximately 1,500 MW of voltage-sensitive load, was used as the primary study scenario. Dynamic simulations were performed to examine voltage and frequency responses at key buses and load areas, and the model behavior was compared with observed system performance. This approach allows the study to evaluate whether existing composite load modeling methods can reasonably reproduce the disconnection and reconnection characteristics of large data center loads during severe system events.

Initial results show that the composite load model provides a useful framework for representing aggregate data center behavior, but also reveal limitations in matching the full ride-through and recovery characteristics seen in actual events. The study emphasizes the importance of load composition, protection settings, and voltage sensitivity in determining the system response. These findings support continued refinement of data center load modeling and provide a foundation for future work on improved parameterization and alternative model structures. This project contributes to ongoing efforts to better represent emerging large electronic loads in planning studies and to strengthen grid resilience as data center penetration continues to grow.

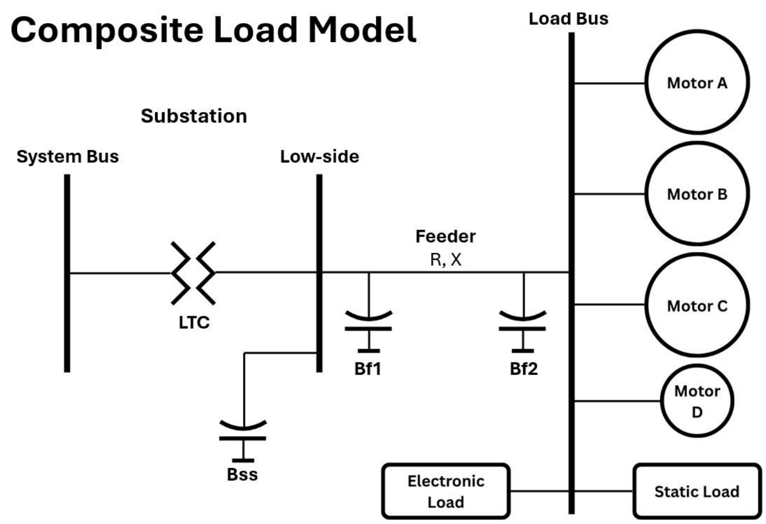


Figure 1: Visual representation of CMLD model developed by WECC.

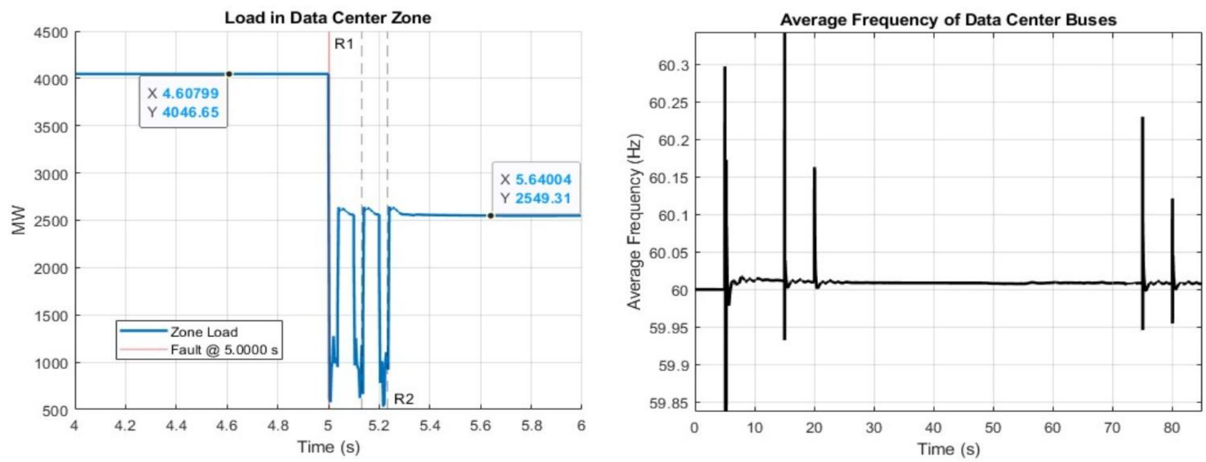


Figure 2: Load and frequency response from event simulation for the data center zone.

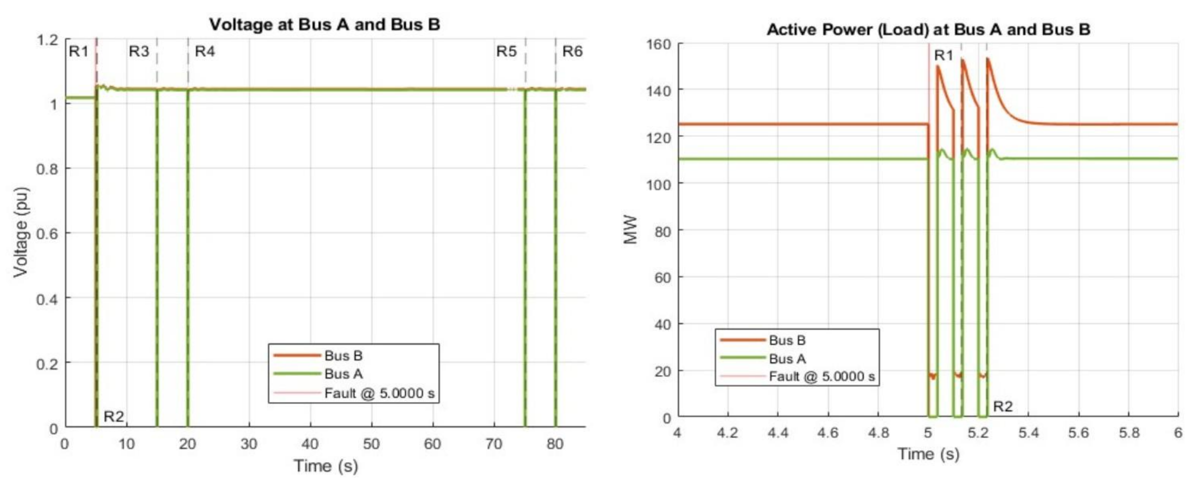


Figure 3: Voltage and load response from event simulation for the buses on either side of the line fault.

Detection of Large Load Loss Event: Focus on the Northern Virginia Data Center Hub

Project Lead: Yilu Liu (UTK) **Graduate Students and Research faculty/associates:** Qian Liu (UTK)
Project Duration: 10/2024 – 2026
Funding Source: National Science Foundation

Summary

A phase-to-ground fault on a 230 kV transmission line in Northern Virginia's Loudoun County on July 10, 2024, led to the transfer of about 1,500 MW of data center load to backup diesel generators. Voltage profile observations suggest that many large load facilities-initiated load transfer when local voltage dropped below a critical threshold.

This finding guided the deployment of additional monitoring units in the area, which subsequently captured multiple similar load-trip events over the following year, further confirming the strong association between large load-loss events and data center operations in the Loudoun County corridor.

By extending the FDR units deployment surround by Loudoun County data center farm, we're able to capture more events starting from 2025. And most of the cases appear to be data center detecting a single voltage dip, and they initiate drop in load profile but recover gradually.

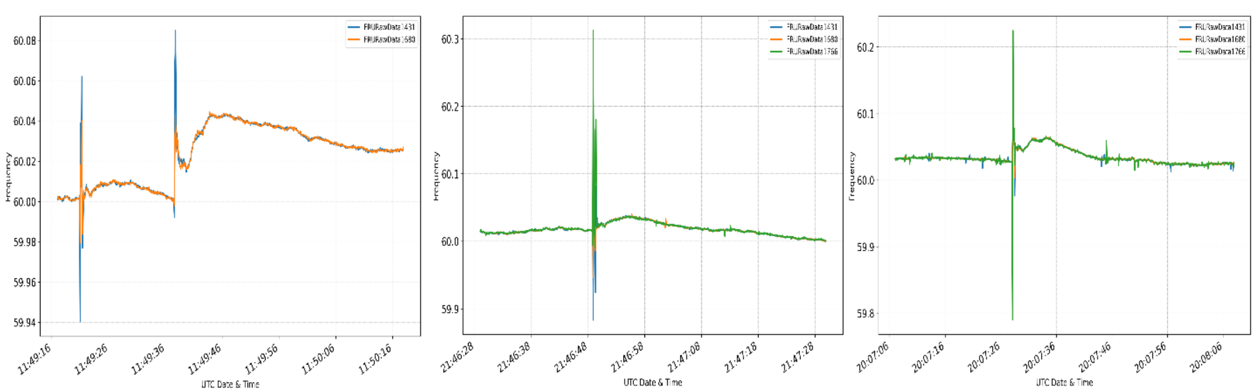


Figure 1: Data Center Load Loss Events in 2025

Bridging PMU Measurements and Dynamic Simulation for Oscillation Analysis

Project Lead: Yilu Liu (UTK) **Graduate Students and Research faculty/associates:** Qian Liu (UTK)
Project Duration: 2/2025 – 2026
Funding Source: Florida Power Light

Summary

Low-frequency oscillations continue to challenge large power systems, making persistent mode identification essential for effective monitoring and control. Using long-term FNET/GridEye measurements, this paper combines ARMA-based ambient modal estimation and oscillation event analysis with large-scale PSS®E simulation to identify and validate dominant modes in the Eastern Interconnection, especially in Florida. The proposed workflow connects field measurements with dynamic simulation and supports improved understanding of oscillatory behavior and future damping control design.

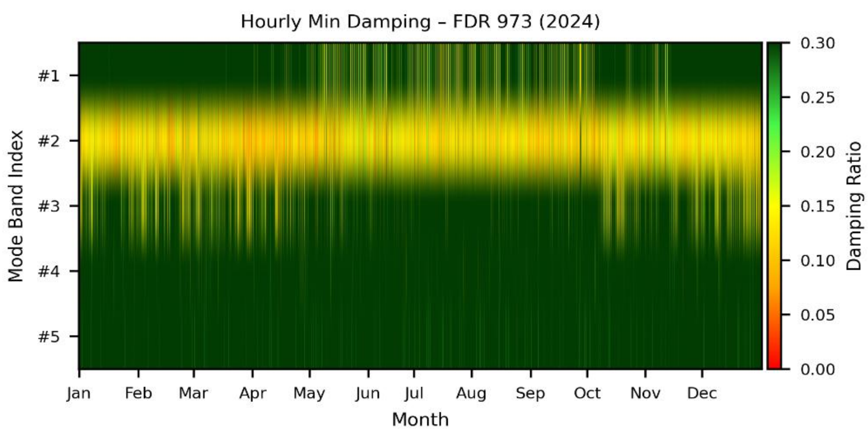


Figure 1: Hourly Damping by Mode

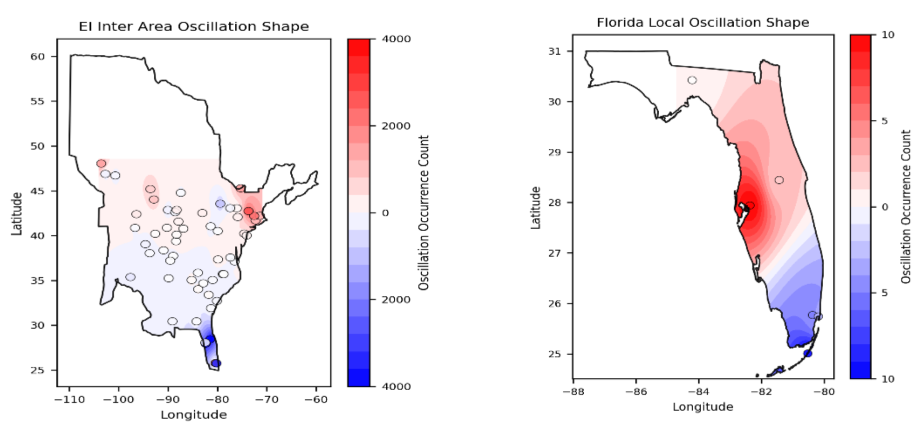


Figure 2 : Mode Spatial Shape by Event Occurrence

ARMA-based modal estimation is applied to ambient frequency data using a 20-minute window. Fitting an ARMA model to each window, modal frequency and damping can be extracted, allowing weakly damped oscillation modes to be identified under normal operating conditions.

PSS®E dynamic simulations were performed for 10 contingencies under spring, summer, and winter operating cases to evaluate the oscillatory response and compare seasonal modal behavior.

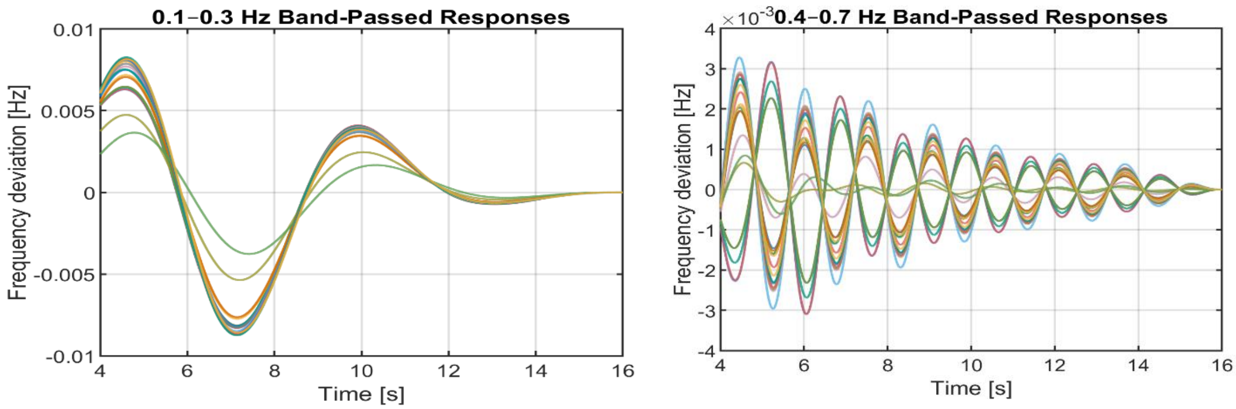


Figure 3 Frequency after Bandpass