U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2024 PROJECT PEER REVIEW
U.S. DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGIES OFFICE

08/06/2024

EE0008956.0003 - Optimal Operation and Impact Assessment of Distributed Wind for Improving Efficiency and Resilience of Rural Electricity Systems

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Wind Utility Consulting

FY24 Peer Review - Project Overview

Project Summary:

- ❑ Supports WETO's Distributed Wind Systems Integration R&D focus area through optimization and control for leveraging distributed wind and other DERs to shave peak demand, restore outages, and mitigate the operational vulnerability in rural grids.

Key project partners: (1) Electric Power Research Center, (2) Algona Municipal Utilities (AMU), and (3) Wind Utility Consulting

Progress made during the review period:

- ❑ Technical feasibility studies on peak shaving, voltage regulation, and restoration.
- ❑ Fenway SCADA upgrade of AMU's three wind turbines.
- ❑ Field survey for installation of AMU's utility SCADA.

Overall Project Objectives (life of the project):

- ❑ Reduce peak demand by 20%, eliminate 95% of voltage issues, reduce restoration cost by 20%, and significantly improve voltage/frequency stability margins during restoration.

Project Start: Jul 2020
Expected Completion: Dec 2024
Period of Performance: 3.5 years

DOE Share: $0.94 M Cost Share: $235.5 K
Total Project Budget: $1.17 M

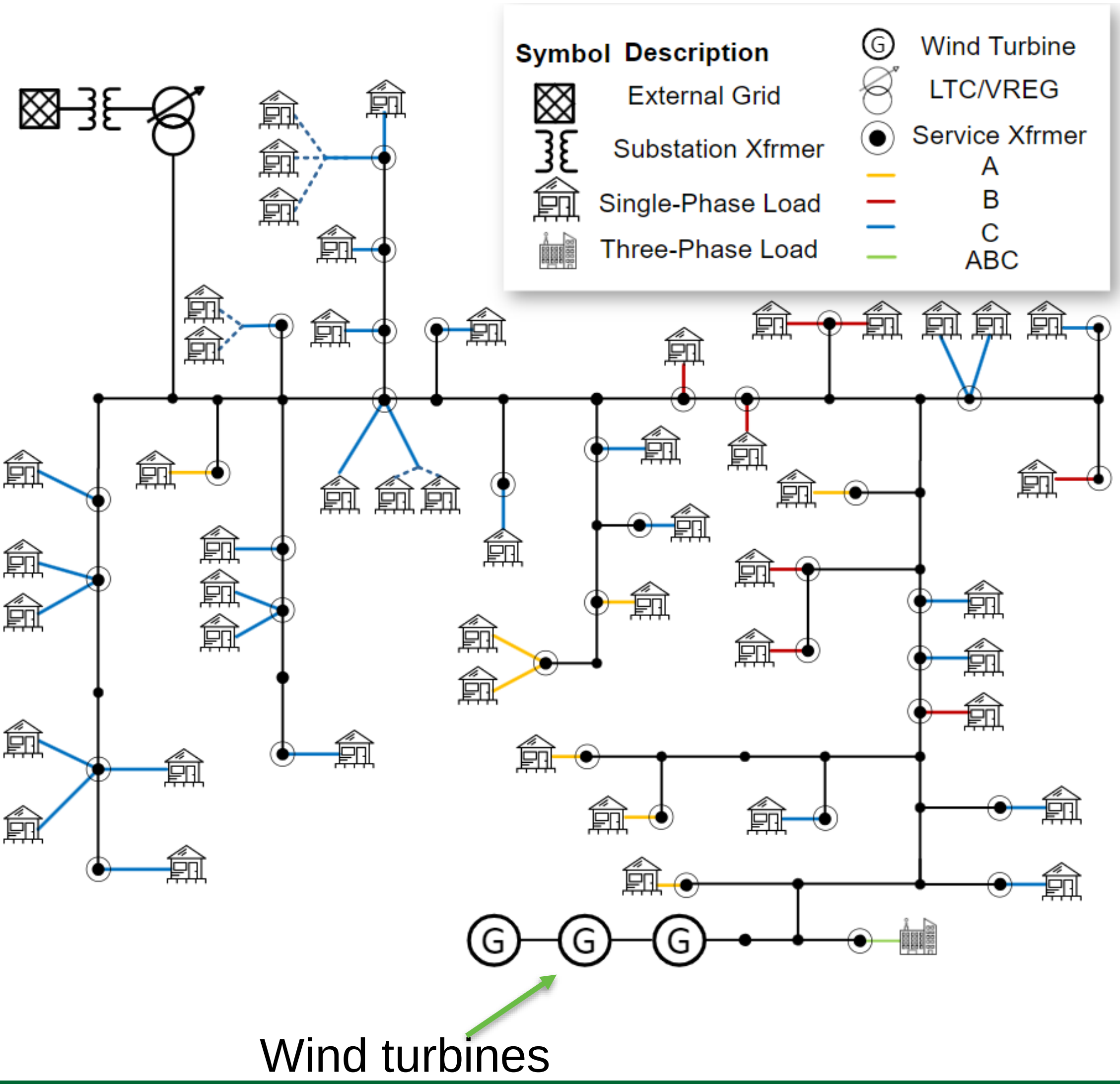
Key DOE Personnel: Patrick Gilman (PM), Bret Barker, Sam Jimenez, and Briana Lynch

Program Performance

Field demonstration – (a) Wind turbine upgrades (completed)

- AMU has two substations: East and West Subs.
- East sub: 9 feeders and West sub: 3 feeders
- Three distributed 750 kW wind turbines are located at the EC3 feeder.
- To enable PF control mode and remote-control capability, we installed
  1. Fenway distributed wind controller
     - Allows data collection and full turbine control
  2. New Turbine Control System card
     - Equipped with operator interface display
  3. New Plug-in CPU card
     - Has 9X computation speed

EC3 Feeder



Project Impacts

Significance of the project:

- ❑ AMU's 3 turbines are installed in 1998 - the first DOE distributed wind project.
- ❑ Given Kossuth County's installation limit, extending existing turbine lifespans is crucial.
- ❑ SCADA upgrade to enable remote control of distributed wind in AMU.

Scientific/Community benefits:

- ❑ Validated technical feasibility of using distributed wind for peak shaving, voltage regulation, and restoration.
- ❑ Improved reliability and resilience, benefiting Algona's residential and industrial customers.
- ❑ Additional operational cost saving, emission reduction, and reduced O&M costs.

Quantitative impacts:

- ❑ Resolve over-voltage issues and reduce voltage fluctuation by >50% in AMU.

Program Performance

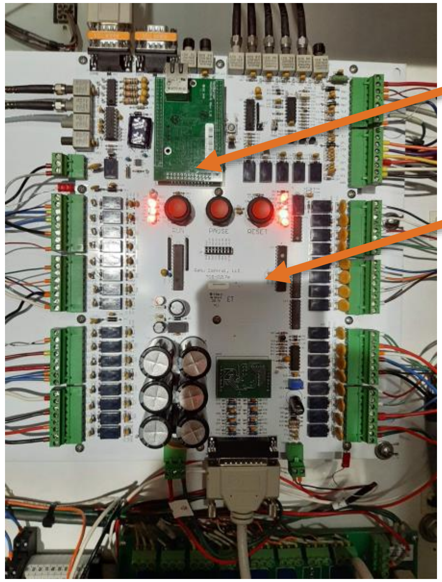
Field demonstration – (a) Wind turbine upgrades (completed)

Old controller

Wintelligence controller

Human Machine Interface (HMI)

New controller

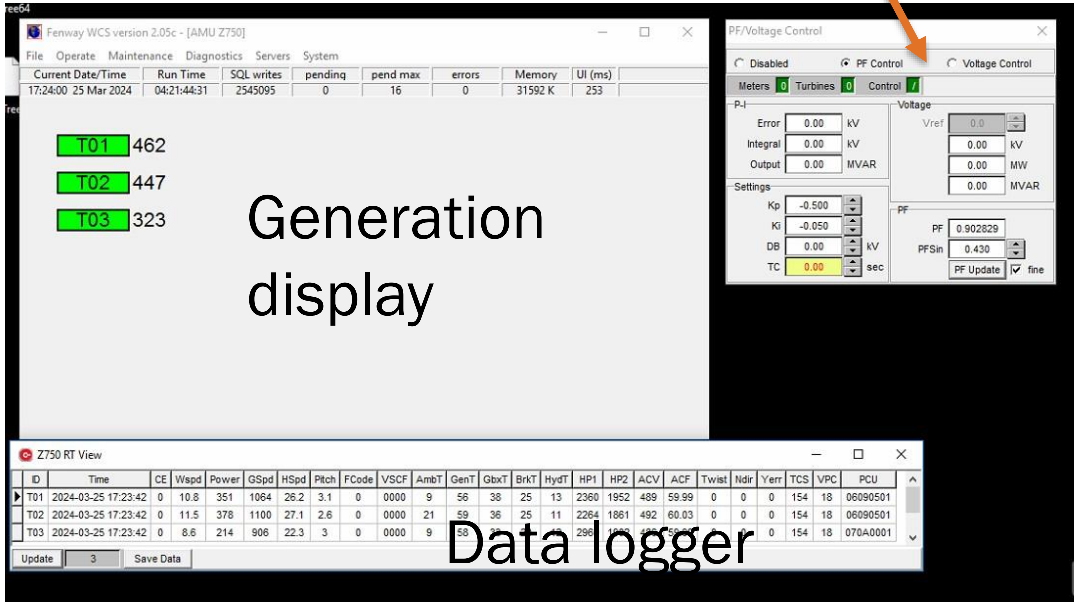


CPU card

Turbine control system card

New HMI

PF and/or voltage setpoint input interface

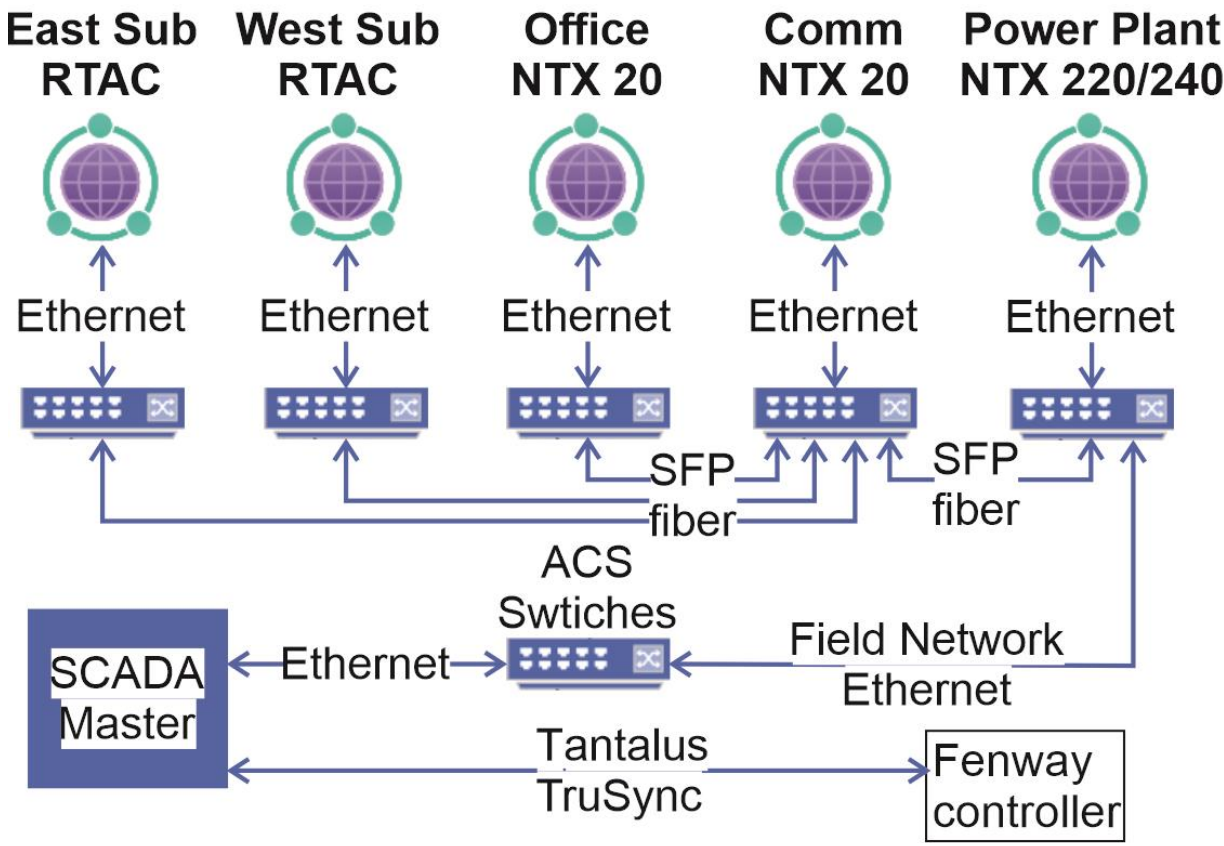


Fenway remote control interface

Project Performance - Upcoming Activities

Field Demonstration – (b) SCADA network upgrade (ongoing)

- ❑ Utility SCADA network design
  - East and West subs will be connected directly to SCADA via SEL RTACs.
  - Plant, Office, and Comm will be connected via Minsait ACS NTX-20 RTUs.
  - All communication will be ethernet-based.
- ❑ Distributed wind communication link
  - Bidirectional data transported from Fenway to SCADA using DNP3 over the Tantalus network.
  - Fenway controller communicates with turbines using Modbus.
  - SoftRTU will help to convert Modbus to DNP3 protocol.



Program Performance – Scope, Schedule, Execution

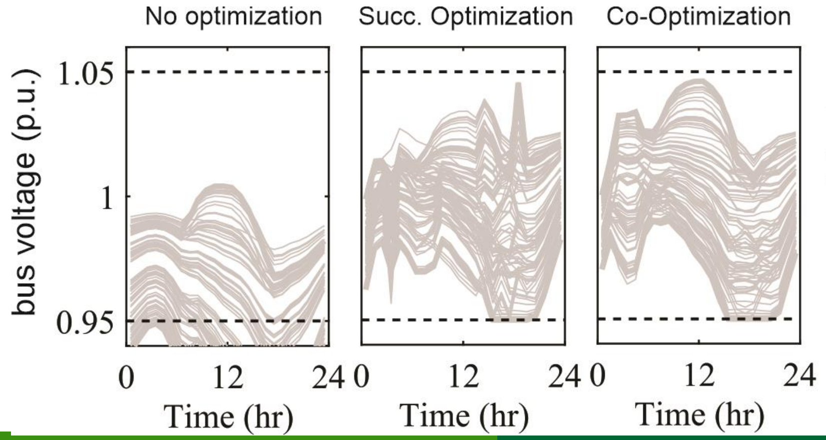
Cooperative Peak Shaving and Voltage Regulation in Unbalanced Distribution Feeders

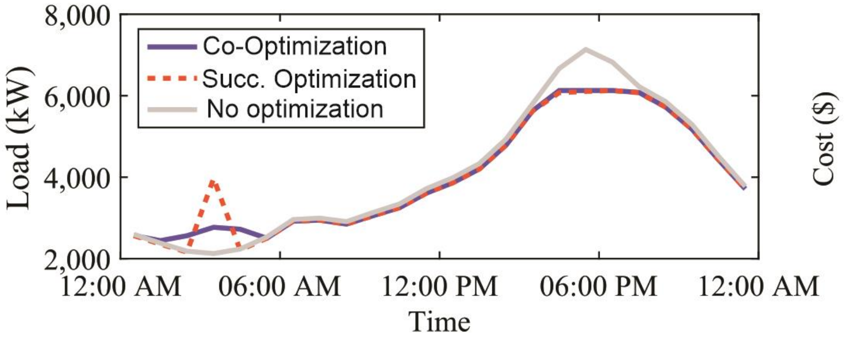
- Objective: Determine the optimal operation of LTC, capacitor bank, and battery storage to minimize energy purchase cost and peak demand under the uncertainty of load, distributed wind and other renewable DERs.
- High-level objective: $\min_{x}(C_{bat}+C_{tap}+C_{cap})+\min_{y}\mathbb{E}_{\xi}\{C_{ele}(y(\xi))\}$

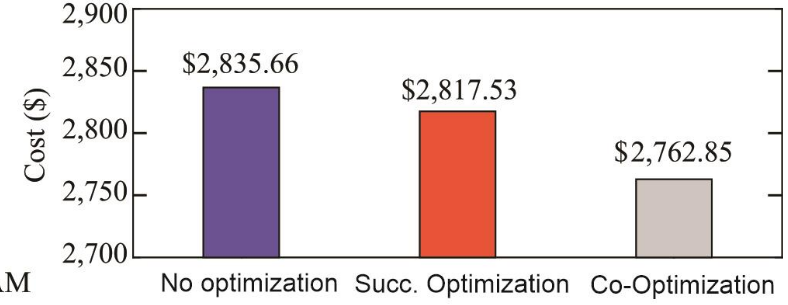
  subject to: peak demand, voltage, power flow constraints

Here, the first stage minimizes the operation cost of equipment, whereas the second stage minimizes energy cost.

- Challenge: Solving the mixed integer problem with the uncertainty set (ξ).
- Solution: Scenario generation and reduction of uncertain variables to convert the problem into mixed-integer second-order cone program (MISOCP), which is then solved using CPLEX.
- Key results: Comparison between (a) no optimization (b) successive optimization, and (c) cooperative optimization







Program Performance – Scope, Schedule, Execution

Data-Driven Robust Volt/Var Control in the distribution system

- Objective: To achieve distributed real-time volt/var control utilizing smart inverters functionality of DERs by leveraging the data-driven voltage sensitivities to real/reactive power injections.

Pre-requisite: Day-ahead optimization provides a voltage set-point at every time step utilizing the prediction of renewable DERs.

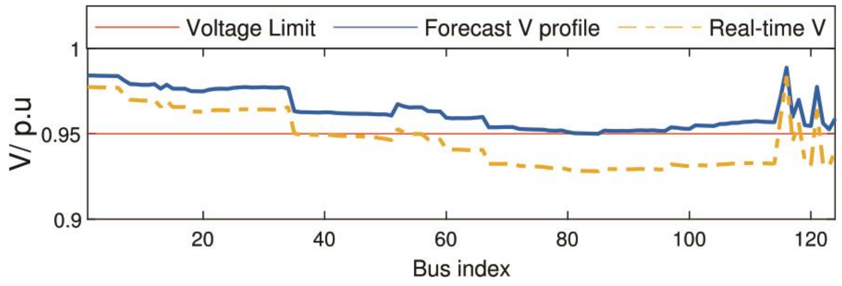
- High-level Objective: Minimize the deviation from reference voltage provide by day-ahead optimization.

i.e,. $min \sum_{i=1}^{n} |\Delta V_i|$ subject to: $\Delta V_i = \sum K_{ij}^{p} \cdot \Delta p_j^{g} + K_{ij}^{q} \cdot \Delta q_j^{g}$, where K_{ij}^{p} and K_{ij}^{q} are voltage sensitivity to active/reactive power.

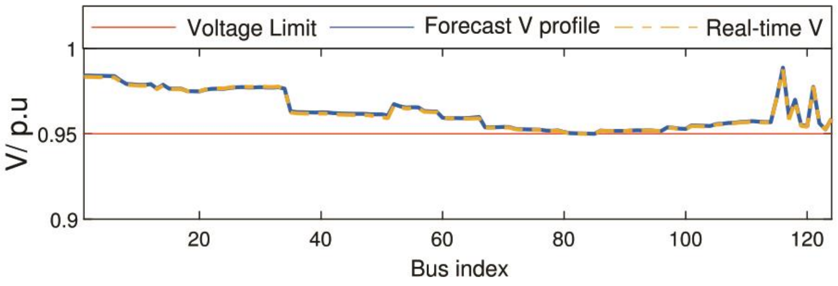
- Challenge: (a) to estimate ultrafast voltage sensitivity factors, (b) to formulate a distributed solution.
- Solution: (a) We trained Deep Neural Network to estimate K_{ij}^{p} and K_{ij}^{q} based on the real-time measurements

  (b) We solved the problem using Alternating Direction Method of Multipliers (ADMM)
- Key results:

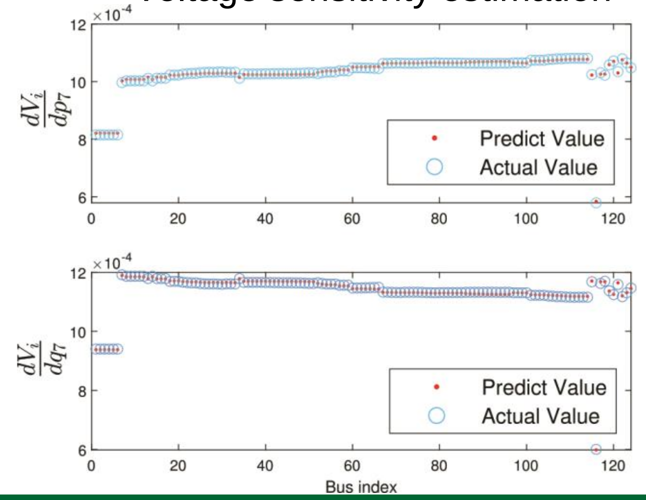
Worst Voltage without real-time control



Worst Voltage with real-time control



Voltage sensitivity estimation



Program Performance – Accomplishments & Progress

- Scientific publications
  - 15 IEEE Transactions
  - 5 Conference papers, with a **Best Paper** award at IEEE PES General Meeting, 2023.
- Key results:
  - Complete modeling all 12 feeders of AMU in OpenDSS.
  - Complete stochastic optimization framework that can regulate voltage and reduce peak demand utilizing distributed wind and other DERs.
  - Complete restoration framework that can pick up load utilizing DERs satisfying frequency stability constraints.
  - Complete Fenway controller upgrade that can remotely monitor and control the distributed wind turbines.
  - Complete field survey report confirming the final design of AMU's SCADA and cost estimates.

Stakeholder Engagement & Information Sharing

Industry Advisory Board (IAB)
Algona Municipal Utilities, Wind Utility Consulting, Central Iowa Power Cooperative, Corn Belt Power Cooperative, and Iowa Lake Electric Cooperative

Stakeholders	Roles and responsibilities
Algona Municipal Utilities (AMU)	Field demonstration
Wind Utility Consulting (WUC)	Advise research works, economic assessment, and field demo.
Minsait ACS	Upgrade utility SCADA
Fenway	Deploy distributed wind controller for remote control capability.

- ❑ On-demand meetings with IAB for feedback on the research idea.
- ❑ 14 regular quarterly meetings with all stakeholders.
- ❑ Quarterly virtual meetings with all stakeholders to share work progress.
- ❑ 4 meetings between AMU, WUC, and Fenway while upgrading the wind turbine controllers.
- ❑ 5 meetings between AMU, WUC, and ACS to design a utility SCADA upgrade plan.
- ❑ ACS traveled to Algona for a field survey to for the SCADA upgrade.
- ❑ 20 publications on top journals and international conferences.

List of publications

[1] Z. Mg et al., "Nonlinear Multiple Models Adaptive Secondary Voltage Control of Microgrids," IEEE Trans. Smart Grids, 2021.
[2] Q. Zhang et al., "Multi-Agent Safe Policy Learning for Power Management of Networked Microgrids," IEEE Trans. Smart Grids, 2021.
[3] Q. Zhang et al., "A Two-Level Simulation-Assisted Sequential Distribution System Restoration Model with Frequency Dynamics Constraints," IEEE Trans. Smart Grids, 2021.
[4] Q. Zhang, "Distributed Optimal Conservation Voltage Reduction in Integrated Primary-Secondary Distribution Systems," IEEE Trans. Smart Grids, 2021.
[5] Y. Guo et al., "Cooperative Peak Shaving and Voltage Regulation in Unbalanced Distribution Feeders," IEEE Trans. Power Syst. , 2021.
[6] A. Arif et al., "Switching Device-Cognizant Sequential Distribution System Restoration," IEEE Trans. Power Syst., 2022.
[7] R. Cheng et al., "An Online Feedback-Based Linearized Power Flow Model for Unbalanced Distribution Networks," IEEE Trans. Power Syst., 2022.
[8] R. Cheng et al., "Online Voltage Control for Unbalanced Distribution Networks Using Projected Newton Method," IEEE Trans. Power Syst., 2022.
[9] Z. Ma et al., "Robust Conservation Voltage Reduction Evaluation Using Soft Constrained Gradient Analysis," IEEE Trans. Power Syst., 2022.
[10] R. Cheng et al., "Automatic Self-Adaptive Local Voltage Control Under Limited Reactive Power," IEEE Trans. Smart Grids, 2022.
[11] Z. Ma et al., "Safe and Stable Secondary Voltage Control of Microgrids Based on Explicit Neural Networks," IEEE Trans. Smart Grids, 2023.
[12] N. Shi et al., "Data-Driven Affinely Adjustable Robust Volt/VAr Control," IEEE Trans. Smart Grids, 2023.
[13] Q. Zhang, "Tractable Data Enriched Distributionally Robust Chance-Constrained Conservation Voltage Reduction,"IEEE Trans. Power Syst., 2024.
[14] Z. Ma et al., "Singular Perturbation-Based Large-Signal Order Reduction of Microgrids for Stability and Accuracy Synthesis With Control," IEEE Trans. Smart Grids, 2024.
[15] Z. Ma "Analytical Large-Signal Modeling of Inverter-Based Microgrids with Koopman Operator Theory for Autonomous Control," IEEE Trans. Smart Grids, 2024.
[16] R. Cheng et al., "Fast ADMM-Based Hierarchical and Decentralized Volt/VAr Control in Distribution Networks," PESGM, 2022.
[17] F. Bu et al., "A Time-series Distribution Test System based on Real Utility Data." NAPS, 2019.
[18] N. Shi et al., "Analyzing Impact of BESS Allocation on Hosting Capacity in Distribution Networks," NAPS, 2022.
[19] S. Maharjan et al., "Robust Model Predictive Techno-Economic Control of Active Distribution Networks," PESGM, 2023. (Best Paper)
[20] P. Tiwari et al., "Assessment of Voltage Balancing in Distribution Networks with Utility-scale and Behind-the-Meter PVs Considering Service Transformers," NAPS, 2023

Thank you

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