



# Distributed Energy Resources – modeling, control, optimization, and data

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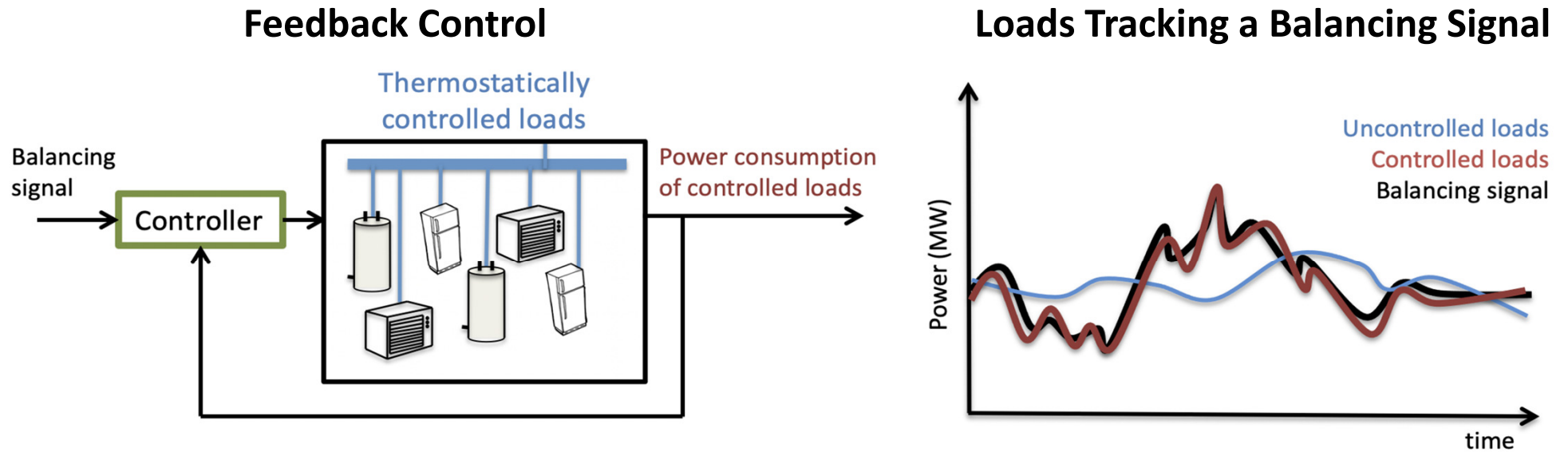


Thanks to NSF, ARPA-E, DOE, and the Sloan Foundation for supporting this work.

# Research on Distributed Energy Resources

- DERs: distributed generation, distributed energy storage, flexible loads
- Approaches to schedule and control aggregations of **battery systems** to provide multiple local/grid services simultaneously
- Approaches to control **solar PV inverters** to inject reactive power to improve phase unbalance in distribution networks (with NRECA)
- Efficiency implications of **commercial building** load shifting
- Impact of **batteries** providing frequency regulation on energy markets
- Aggregate modeling and control of **flexible loads, especially thermostatically controlled loads**, for ancillary services

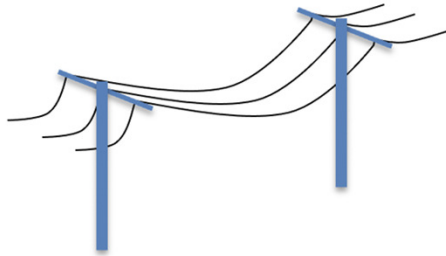
# Example: Electric Load Coordination



**Thermostatically controlled loads** include air conditioners, electric water heaters, heat pumps, and refrigerators – they are a prime candidate for load coordination because they can be used to store thermal energy.

# Recent ARPA-E Project: Establish credibility for load control at scale

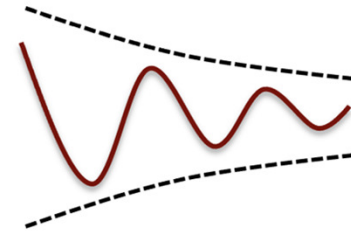
Network-Aware



Communication-Constrained



Stability Guarantees



## Controllers that enable aggregations of air conditioners to provide frequency regulation

... with sufficient quality to meet an ISO's performance requirements

... with no stability or distribution network issues

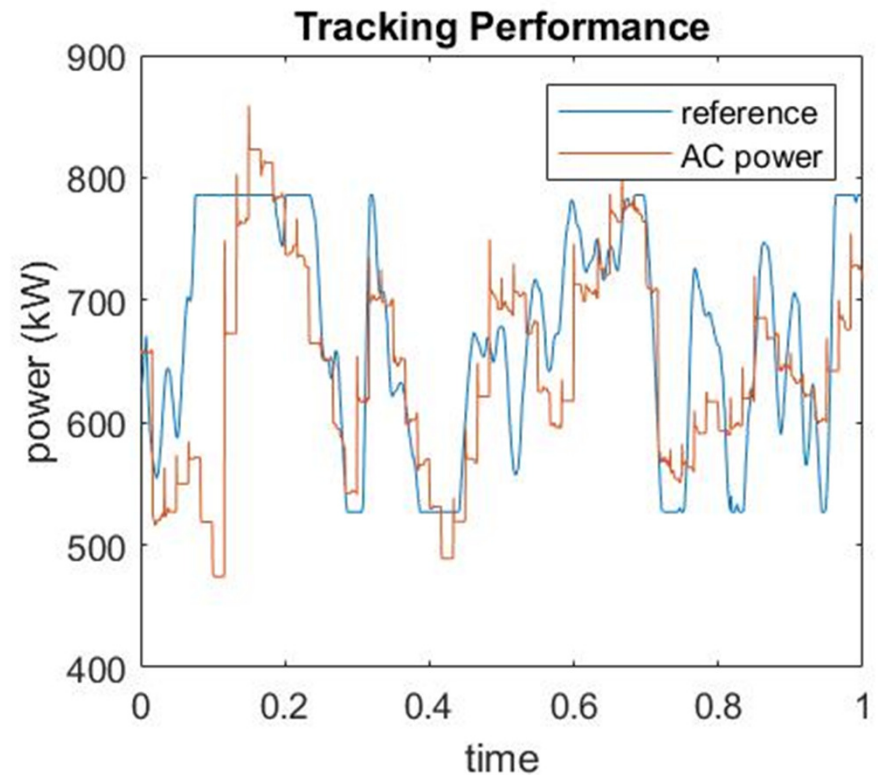
... utilizing low-cost communication network(s) and controllers

... in a way that is completely non-disruptive to customers

... AND cost/benefit analysis shows profitability for aggregator and consumers

# Why Frequency Regulation?

- It's really hard – if we can demonstrate frequency regulation, we should be able to do any balancing service.
  - Requires coordination amongst loads
  - Requires closing the loop fast (2-10 seconds)



Reference above is a PJM Frequency Regulation Signal

# Approach:

## Test load controllers in 3 testbeds

### Simulation Testbed

1000 ACs

(high-fidelity models)

+ distribution network (GridLAB-D)

+ comm network (fully configurable)



### Experimental Testbed

20 real

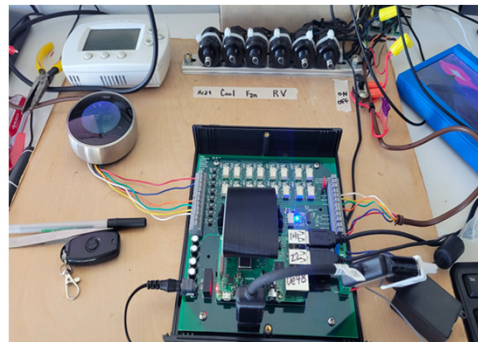
ACs

at LANL



### Field Testbed

100 real ACs



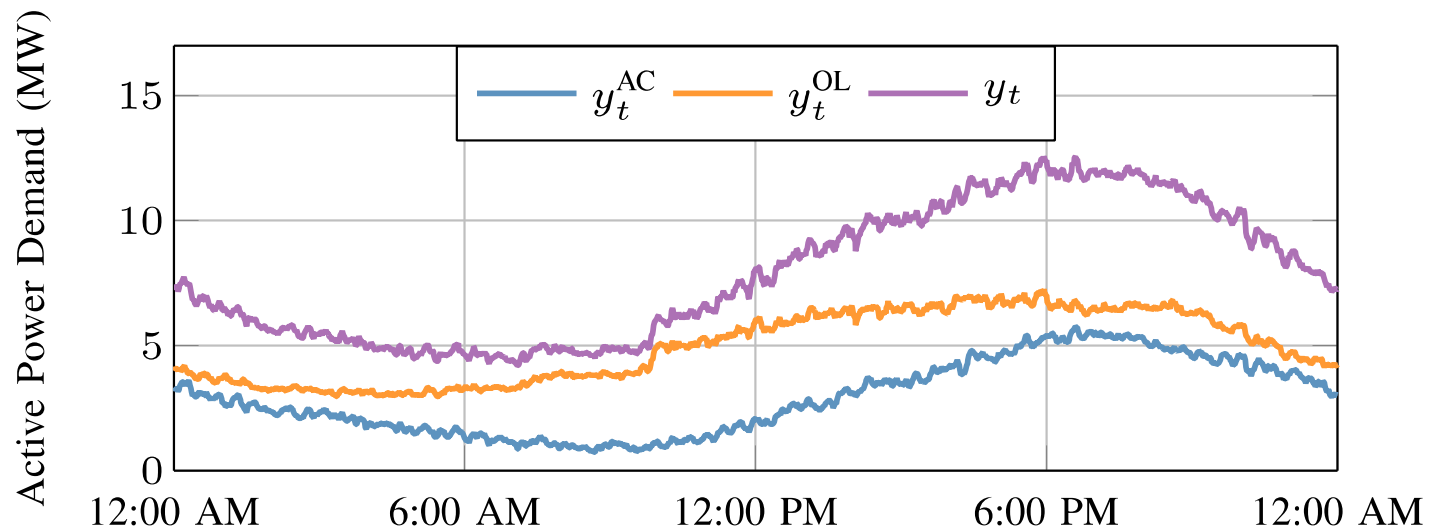
Validate!

# Key issue 1: DER Modeling & Estimation

- Utilities/aggregators/researchers need DER models for use in forecasting, operations, and real-time control
  - Physics-based vs. Data-driven?
  - Individual vs. Aggregate?
  - Static vs. Dynamic?
  - (...and how do DERs/inverter-interfaced devices affect grid dynamics and how we should model the grid itself?)
- Feeder Energy Disaggregation – in real-time, estimate the break down of net load by type, e.g., air conditioning load, EV load, PV production, etc.

# Key issue 1: DER Modeling & Estimation

## Problem Formulation



- Measure the purple (load at the feeder)
- Estimate the blue (net air conditioning load)

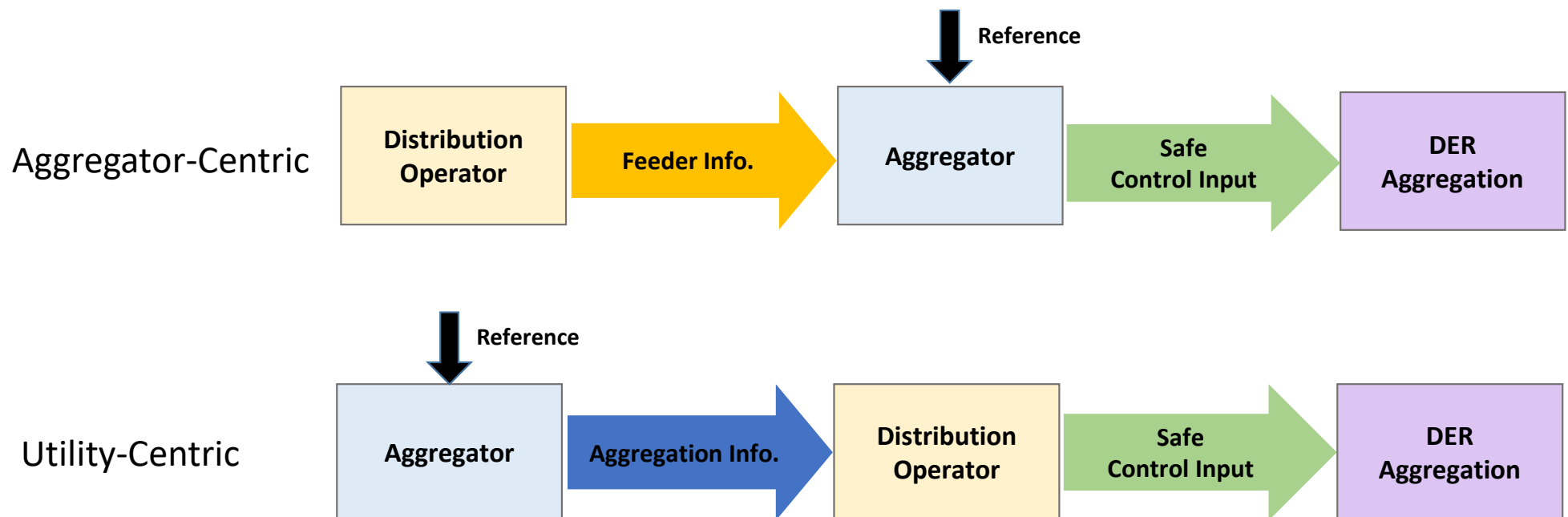
Ledva, Balzano, and Mathieu, “Real-time Energy Disaggregation of a Distribution Feeder’s Demand using Online Learning,” IEEE Transactions on Power Systems, 2018.



## Key issue 2: Network-Aware DER Coordination

- Division of responsibilities...
  - Distributed Network Operator (Utility)
    - Responsible for safe operation of the distribution network
  - Third-party Aggregator
    - Coordinates/controls DERs to provide grid balancing services
- Coordination between the utility and the aggregator is necessary for network-safe grid balancing services from DERs, see e.g., FERC 2222.
- The utility is not willing to share detailed network information with the aggregator.
  - Network-safe grid service should be conducted without sharing either entity's private information.

# Key issue 2: Network-Aware DER Coordination Frameworks



[S. C. Ross, N. Ozay, and J. L. Mathieu, IEEE PowerTech 2019]

## Key issue 3: Energy Equity & Justice

“Energy justice refers to the goal of achieving equity in both the social and economic participation in the energy system, while also remediating social, economic, and health burdens on those historically harmed by the energy system (“frontline communities”). Energy justice explicitly centers the concerns of marginalized communities and aims to make energy more **accessible, affordable, and clean** and democratically managed for all communities.”



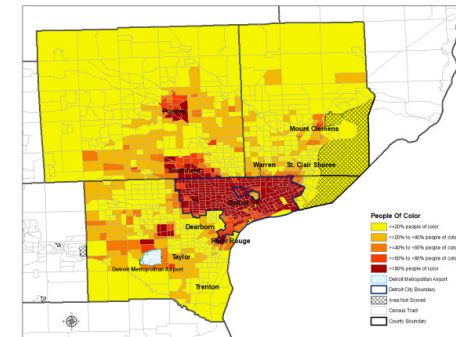
Initiative for Energy Justice, “Section 1 – Defining Energy Justice: Connections to Environmental Justice, Climate Justice, and the Just Transition,” <https://iejusa.org/section-1-defining-energy-justice/>,

# Key issue 3: Energy Equity & Justice Research Agenda

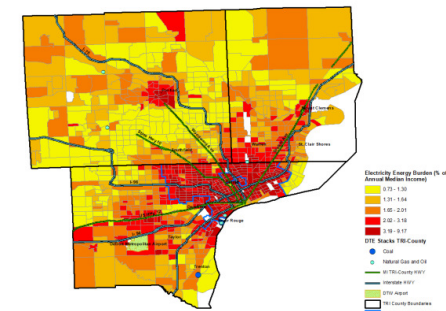
1. Equitable electricity system planning
2. Equitable electricity system operation and control
3. Equitable DER adoption and coordination
4. Equitable electricity rate and demand-side management program design
5. Reducing bias in data-driven algorithms for power systems
6. Recommender systems for electricity rates and demand-side management programs

J.L. Mathieu. "Algorithms for Energy Justice". In: Women in Power: Research and Development Advances in Electric Power Systems, Springer Women in Engineering and Science Series. Ed. by Jill S. Tietjen, Marija D. Ilic, Lina Bertling Tjernberg, and Noel N. Schulz. Springer Nature Switzerland AG, Cham, Switzerland. 2023. [Available on my website.]

Detroit, MI



Distribution of people of color



Distribution of energy burden

Source: UM, Via:  
<https://planetdetroit.org/2021/05/mpsc-considers-how-to-account-for-the-inequitable-public-health-costs-of-future-electricity-generation/>

# Concluding Thoughts

- Key issues
  - DER Modeling & Estimation
  - Network-Aware DER Coordination
  - Energy Equity & Justice + DERs
- A need for more data – access to existing data, generation of new data
- A need for more collaboration – industry, labs, academia

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